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ECONOMIC BALANCES OF SMALL SCALE ETHANOL FROM BIOMASS OPERATIONS

by

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[1] Prepared under contract from the Illinois Department of Energy and Natural Resources as Project Number 80.224 by the University of Illinois, Department of Forestry and Department of Agricultural Economics, Urbana, Illinois 61801.

Printed by Authority of the State of Illinois

Quantity Printed: 350

Date Printed: July 1982

This report has been reviewed by the Department of Energy and Natural Resources and approved for publication. Views expressed are those of the contractor and do not necessarily reflect the position of DENR.

One of a series of research publications published since 1975. This series includes the following categories and are color coded as follows:

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Abstract

The economics of three operating fuel ethanol from grain facilities in and around Illinois, with rated production capacities of between 625 thousand to 1.5 million gallons per year, were evaluated. Results on capital costs, operational experiences and marketing of fuel ethanol and feed by-products are presented. All three plants analyzed were found to have low indirect costs due to the acquisition of used tanks and other equipment, which improved their operational viability. An analysis was conducted of the sensitivity of production costs to changes in costs of inputs, and, assuming uncertainties in inputs, the total uncertainty in product costs. Besides the cost of grain and fuel energy, the most important factor in cost was the "duty cycle", the fraction of total capacity actually realized. This factor was found to be less than one for all operations studied. Those plants studied producing lower proof hydrated ethanol were found to have limited markets for their fuel product. Subsequently, many of these facilities opted to install dehydration equipment, which typically compounded cash flow problems. Due to a variety of changes in economic and marketing factors, the economic attractiveness of a grain-based ethanol plant of the size examined in this study appears limited.

I. Introduction

The economic viability of fuel ethanol from grain production depends, to some extent, on the scale of production. Some studies have shown increased returns to scale until the one hundred million gallon per year level is reached [Noyes Data Corp., 1979]. The question naturally arises as to whether all fuel ethanol production should be concentrated in these large scale plants. Or, are there factors at work which may also make smaller size plants economically viable. This study was undertaken to answer that question for plants in the one to fifteen million gallons per year category by a gathering and analysis of actual operational data from plants of this size which use corn as a feedstock.

Locating fuel ethanol plants of this type in the Midwest which were actually operating in 1981 was more difficult than anticipated. There has been a wealth of misinformation generally in the fuel ethanol business, and this has been especially true in reports on which facilities are planned, under construction, actually producing, or already shut down. An exhaustive search of the Illinois, Iowa, Missouri, Wisconsin, Indiana and Michigan areas located only three plants in this category which were actually operational as of December 1, 1981.

Additionally, an ACR Process designed plant in Storm Lake, Iowa, with an annual capacity of 2,500,000 gallons of 199^+ proof ethanol, and the 10,000,000 gallons per year plant of Michigan Agri Fuels in Alma, Michigan were both due on stream in late December of 1981 or January of 1982.

There are several possible explanations for the scarcity of operational plants in the Midwest in the one to fifteen million gallons per year category in 1981. Economics of scale are such that fuel ethanol producers using the more capital intensive, but also more flexible wet milling process would not consider building a plant with less than a fifteen million gallons per year capacity. On the other hand, many of the earliest enthusiasts of fuel ethanol production did not have enough capital to build plants with capacities of over one million gallons per year.

Many of these early enthusiasts assumed there would be a market for 190° (proof) fuel ethanol and built plants with less than 500,000 gallons per year capacities, with no facilities for upgrading the ethanol to the 200° (proof) necessary for use in ethanol/gasoline blends.[1] Most of these plants have faced severe economic difficulties, have operated sporadically, and in some cases, already shut down.[2]

As it became clearer that the ability to produce 200° ethanol was a necessity, the estimates of economically viable plant sizes increased from earlier projections. The capital expense necessary to install 199^+ proof distillation systems employing proven technology, required larger productive capacities to avoid prohibitive per gallon costs for drying the ethanol; i.e., there are definite economies of scale for drying.

With larger productive capacities, state tax exemptions for fuel ethanol became an important consideration in plant location. Construction of plants in the one to fifteen million gallons per year range has tended to be in those states which passed the largest fuel ethanol tax exemptions early.

An extreme example of this trend is illustrated by the complete lack of operating plants of this size in Illinois in 1981. Illinois did not have a state tax exemption for fuel ethanol until June of 1981, when its relatively unattractive and yearly declining tax exemptions came into effect.

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[1] The notation 200° will be used in this report to refer to ethanol above 199.5°.

[2] In Illinois, producers of 190° ethanol have been forced to ship their ethanol out of state for drying since ADM in Decatur discontinued buying from them in early 1981. According to an ADM spokesman, they stopped buying 190° ethanol from other producers because they could not market all the ethanol they themselves could produce. The fact that some ethanol from small producers contained impurities which could at times cause fouling problems in their distillation columns was not a major factor in the decision to stop buying 190° ethanol for upgrading. Illinois producers have shipped 190° ethanol to Minnesota, Michigan, Indiana, Virginia and Georgia in 1981, with shipping charges of from 8¢ to 22¢ per gallon and a sales price of from $1.45 to $1.51 at these locations. The net to these producers was as low as $1.23 per gallon and as high as $1.43.

With the start-up of the joint CPC-Texaco plant in Pekin, Illinois (Pekin Energy Corporation) with an annual capacity of 60 million gallons, Illinois became the clear leader in U.S. fuel ethanol production. However, its productive capacity was concentrated in just two plants (Pekin Energy and ADM in Decatur) which were both located on the sites of previously existing wet milling facilities.

In smaller scale production, no other Illinois plants produced over 100,000 gallons of 190^0 or 200^0 ethanol in 1981, with the possible exception of the Midwest Solvents plant in Pekin, Illinois and the ADM plant in Peoria. Both of these dry milling operations can produce beverage, industrial or 199^+ proof fuel ethanol. But when last contacted in November of 1981, neither plant was producing fuel ethanol. (See Appendix B for a description of Illinois fuel ethanol production facilities.)

ACR Process Corporation of Champaign, Illinois has designed five plants in the U.S. with a 2.5 million gallon annual capacity, which have been built in the following states: Arkansas (effective 6.5¢ per gallon state tax exemption, passed in 1979), Colorado (5¢ state exemption, 1978), Iowa (effective 7¢ state exemption, 1978), Maryland (1¢ exemption, 1979,) and Oklahoma (6.5¢ exemption, 1979) [Fuel From Farms]. There are no ACR Process plants planned in Illinois at present[3/] [Chambers, 1981].

[3/] *State tax exemptions, for fuel ethanol produced and sold within that state, may become less important in the future location of plants because of ADM's successful challenge of the Minnesota law which limited its tax break to Minnesota-produced fuel ethanol. It appears that these state laws are a violation of the interstate commerce clause of the U.S. Constitution, and will be successfully challenged.*

In the one to fifteen million annual capacity category, which will be referred to as medium scale in this report[4] there appear to be two basic types of plants. One is the complete, professionally designed plant, utilizing all new equipment, employing a proven distillation system to produce 200^0 ethanol, a drying system to dry both wet grains and solubles to produce DDGS, some pollution control equipment, and adequate water source and treatment facilities. The capital cost for such plants constructed in 1980 and 1981 has been approximately $2 per annual gallon capacity.

The other type of plant, from which most of the operational data in this report were obtained, are more or less self-designed with some help from professional engineers, utilize some used equipment and other equipment not specifically designed for ethanol production, sell by-product as wet distillers grains at approximately 65 percent moisture, do not recover solubles, are using or have tried somewhat experimental and unproven techniques for drying the ethanol to 200^0, and in two of the three plants, do not have complete water treatment facilities to dispose of waste water. The capital costs per annual gallon capacity has been under $.75 for these plants. However, there has been much "sweat equity" put into construction and modification of these plants, which has not always been included by the owners in their capital cost figures.

In the "complete" plant category, the only medium scale plant located in the Midwest which had actually gone into operation before December 1, 1981 was the plant of Conrad Industries in Bonaparte, Iowa, with a capital cost of $6,000,000 and an annual capacity of 2,800,000 gallons per year. Start-up was in August of 1981, but the plant actually operated for only two full weeks before financing problems, difficulties in selling the 197.5° ethanol output, and troubles with coal handling equipment for the fluidized bed combustion chamber led to a halt in production in September of 1981. There were plans to reopen with new equity financing in early December of 1981. When visited in August of 1981, the plant was not operating due to problems with the coal handling equipment.

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[4] *The Bureau of Alcohol, Tobacco and Firearms classifies production from 1 to 9,900 gal./yr. as small, from 10,000 to 499,999 as medium, and over 500,000 as large. Small producers must make yearly reports to the BATF; medium producers report semiannually and large producers report quarterly. As of September 1981, the only Illinois producer to make quarterly reports has been ADM. In common usage, considering the capacities of plants built, medium scale seems to be the best descriptive term for plants in this category.*

The two distinctive features of the Conrad Industries plant --the use of coal as a fuel, and the vacuum distillation process seem to have caused the most problems during its start-up period. If the coal system works according to plans, the fuel cost of approximately 11¢ per gallon produced would be significantly lower than costs for users of natural gas and propane.

The vacuum distillation process which has been cited in fuel ethanol literature as a promising method for low cost production of 200° ethanol, may pose more serious problems. The original literature on the Conrad Industries plant indicated that 199^{+} proof ethanol would be produced by the vacuum process alone [Conrad 1981]. In actual operation, the plant produced 197.5° ethanol, which it had difficulty marketing, even though some studies have shown no phase separation at -22°F for 10 percent ethanol gasoline blends using ethanol above 196° [Gasohol U.S.A., December 1979].

Distributors were wary of buying the 197.5° output, and Conrad Industries is planning to install dehydrators using molecular sieves to upgrade the ethanol to 200°. The experience at this plant should lead to some caution in plans for use of the vacuum distillation process in other plants. Data from the Conrad Industries plant has not been included in this report because of the short duration of the plant's actual operation in 1981.

In the low capital cost, self-designed, "incomplete" plant category, data were obtained from three plants. These are Mid States Energy Resources of Lanark, Illinois with an annual capacity of 625,000 gallons of 200° ethanol. Food and Energy, Inc. of Litchfield, Michigan with an annual capacity of 1,200,000 gallons and another midwestern plant, which chose to remain unidentified, with a capacity of 1,500,000 gallons per year of 192° ethanol. This plant will be referred to as Plant X in this report. Annual capacities were estimated by taking the output of the most constraining factor in production, as the plants stood, and assuming 24 hour a day operation for 360 days per year. None of the plants was actually operating on such a schedule, so that the capacities stated are of the highest annual production possible under optimal conditions. The largest monthly production in 1981, by any of these plants, was 72,000 gallons of 192° ethanol by Plant X.

Data from these three plants was obtained by observation of plant operations, information from plant records made available by plant operators, conversations with managers and workers, and telephone updates. Although it had been anticipated at the beginning of this study that several "complete", (or $2 capital cost per annual gallon) plants would be in operation in the midwest, the fact is, that in medium scale production, it was the operators of the low capital cost plants who were actually making fuel ethanol in 1981. As smaller, and sometimes larger producers shut down or curtailed operations, these operators stayed in business. They had several things in common. All had capital costs of between $.50 and $.75 per annual gallon, and all were using fermentation tanks obtained from a closed Blatz brewery in Milwaukee[5/]. All were owner-operated, with the owners at times wielding wrenches and

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[5/] *Used fermentation tanks from closed breweries or distilleries seem to be readily available at a cost of $.25 per gallon capacity, as opposed to the $1.00 per gallon cost of new mild steel tanks. Because of their use in the beverage industry, these tanks are either stainless steel or glass lined (as were the Blatz tanks) and have a continued life expectancy of well over ten years. Their use could also enable producers of fuel ethanol to produce industrial ethanol by modifying their distillation systems. On the other hand, this source is obviously exhaustible.*

screwdrivers, at least one employee in each plant seemed to have exceptional mechanical skills, and all were experiencing cash flow problems.

II. Production Cost Data for Three Plants

Before a description of the operational aspects of each plant, a table of the various costs of production for the plant in $1/gallon, will be presented. In Table 1, three sets of figures are provided. The first column shows the actual operating expenditures as they were observed, and when subtracted from the ethanol sales price, gives an estimation of the plant's actual rate of return. The second column assumes that all capital is debt with a fixed interest rate of 16 percent to be amortized over a ten year period, which is the estimated life span of these plants. This column gives an idea of the financial problems this plant would have faced if it had been forced to fully shoulder the high interest rates of recent times. The third column contains cost figures to be used as the base case for a sensitivity analysis on production costs which will appear later in this report. In establishing base case figures, it was assumed that the plant would operate at full capacity and a real rate of interest of 3 percent is used[6/].

The establishment of a base case using a real rate of interest assumes that after the plant is built, there will be no inflation in either input or output prices. This assumption, although seemingly highly artificial, does give us base case figures which reflect production costs over the plant's estimated ten year lifetime, and the proportion in which the various costs occur. In the case of inflation, results could be expressed in inflated dollars. (See Appendix D.)

[6/] Historically a real rate of return of two percent (that is a nominal rate two percent above the inflation rate) has been demanded by investors in financial instruments. During the past year, the real rate of return has been above five percent at times. The three percent figure chosen for the base case assumes that real interest rates will be above the historical average, but below recent rates.

Using nominal interest rates with a fixed mortgage amortized over ten years, would give a more accurate picture of a typical plants actual financial position in its first year. But use of nominal interest rates such as 16 percent, imply an inflationary scenario and would force one to make assumptions on future rates of inflation. If we assumed a 10 percent a year inflation rate for the next ten years for all costs of production except capital (fixed mortgage payments), production costs for a plant such as Food and Energy operating at full capacity might appear, in current dollars as:

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Capital costs $/gallon	.15	.15	.15	.15	.15	.15	.15	.15	.15	.15
All other production costs $/gallon	1.29	1.42	1.56	1.72	1.89	2.08	2.29	2.52	2.77	3.05
Total Cost $/gallon	1.44	1.57	1.71	1.87	2.04	2.23	2.44	2.67	2.92	3.20
Capital cost as a % of total cost	10.4	9.6	8.8	7.9	7.3	6.7	6.1	5.6	5.1	4.6

Capital cost per gallon would appear to be a smaller percentage of total cost in year ten than in year one. Establishing a base case by using a producers actual fixed mortgage cost as a basis for capital cost per gallon would fix this cost at a higher percentage of total cost than it actually is over the plant's lifetime.

In many of the studies on fuel ethanol production the focus has been on per gallon production costs. Unfortunately, no single figure for these costs can accurately reflect both present production costs and probable per gallon costs over the plant's lifetime. There is a tendency for the casual reader to assume that base case figures, which use a real rate of interest of two percent to three percent, represent actual production costs and there is wonder at the financial problems producers are actually facing. In providing three sets of figures for these plants it is hoped that base case figures will not be mistaken for actual (nominal) costs of production.

Food and Energy Inc.

Food and Energy Corporation, located in a small industrial park just west of Litchfield, Michigan has been one of the earliest and most durable producers in the medium scale range. The plant began opeation in February of 1981, and its maximum monthly production of 200° ethanol during 1981 was the 49,355 gallons produced in August (about 50 percent of capacity).

The plant uses the batch process (700 bushel of corn per batch) and produces 200° ethanol by distillation to 190° and molecular sieve drying. Its by-product, wet distillers grains, is separated from the stillage by a screening process and sold at moisture contents which have ranged from 65 percent to 80 percent, depending on how each batch turned out.

During August, careful records were kept on production input costs, and the preceding chart summarizes the per gallon costs of the 49,355 gallons produced. Water, gas and electric figures were obtained from the month's utility bills. Labor, enzyme and chemical, corn and interest costs, as well as wet distillers grains sales and prices were obtained from plant records or information provided by the management.

The most important factor reflected in the actual cost figures, aside from the price of corn, was the plant's operation at a rate of production well below its capacity of 100,000 gallons per month. There seem to be two major reasons for this. One has been a lack of working capital to make improvements when needed. The other has been an inability to sell all of its wet distillers grains at higher levels of production. Since WDG must be fed within two or three days of production, ethanol production schedules must be closely tied to the sales of WDG at Food and Energy. At times ethanol production has had to be curtailed because all of the WDG, which would have been produced, could not be sold.

Food and Energy has taken a more aggressive approach in marketing its wet distillers grains than the other producers studied, and has at times obtained somewhat higher prices for this product. There is a full time marketing person who visits surrounding farms with samples of WDG and information on the feed value of WDG. Most of this marketing effort is aimed at dairy farmers.

According to the 1974 Michigan Census of Agriculture, there were 52,303 dairy cows located in 1,399 farms in the six county area surrounding the plant. Assuming dairy cows consumed five pounds (dry weight basis) of distillers grains per day as a protein supplement (Kienholz 1980) it would take 1,888 cows to consume the WDG produced when the plant operated at a rate of 600,000 gallons per year as it did in August, or 3,776 cows if it operated at full capacity.

Some animal scientists believe WDG to have a feed value equal to soybean meal on a dry weight basis[7/], so it may seem surprising that Food and Energy has had difficulty selling it at a price of 2¢ a pound below soybean meal. Three factors seem to account for this. One is the newness and general unfamiliarity with feeding WDG. Another is the difficulty in handling it, as it doesn't move properly through most presently installed feeding equipment. And a more serious problem has been farmer's concern over reliability of supply. Should the plant shut down for repairs, or winter weather cause transportation difficulties, farmers could be forced to change feed rations, and these changes are often accompanied by drops in milk production.

Another factor which had hindered production at Food and Energy is the lack of a holding pond or other outlet for the waste water which contains the soluble part of the stillage. At present, water which is no longer reusable must be trucked by tanker, at a cost of $60 per 7,500 gallons to be dumped in farmer's holding ponds or on fields. Partly

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7/ *Larry Berger of the University of Illinois thinks this is the case, as a result of feeding trials he has run. He believes there may be some factor in WDG, which is destroyed in drying it to DDG, which accounts for its higher than expected feed value. Feeding trials are now underway at the University of Illinois to compare WDG and DDG (Berger, 1981).*

because of the cost of this disposal, Food and Energy has tried reusing this waste water in subsequent cooks. During a visit in September, plant operators felt they had been able to overcome the problems of contamination and chemical changes associated with waste water reuse. However, by December they had given up this practice because there had been too many bad batches--that is, batches with low ethanol yields.

The exceptionally high recovery rate of 13.5 pounds per bushel (dry weight basis) of distillers grains during August may have been accounted for by the fact that the water portion of the WDG produced contained a much higher percentage of solubles, because of water reuse, than would ordinarily occur. The 13.5 pounds per bushel of dry matter recovered probably contained about 1½ pounds of solubles and 12 pounds of distillers grains.

The strong point of the Food and Energy plant has been its early and relatively successful use of molecular sieves as a drying agent. The first dehydrator constructed worked successfully for several months, but then after drying a load of 190^0 ethanol from another producer, its output declined quickly to about 50 percent of the original. It is assumed that fusel oils or possibly other compounds in that ethanol permanently impaired the ability of the sieves to absorb water (Saunders 1981). (See Appendix A on molecular sieves.) The first dehydrator has been redesigned, and a second, larger one added. The two dehydrators combined have a capacity to dry around 5,000 gallons of 190^0 ethanol per day, and a considerable profit has been gained by drying 190^0 ethanol purchased from other producers. The wet ethanol has been bought for \$1.45 to \$1.51 per gallon (depending on proof and fusel oil content) and dried at an operational cost of 6.4¢ per gallon (4.7¢ natural gas, 1.7¢ electricity). During August of 1981, 15,902 gallons of 190^0 was purchased and dried. Fuel and electricity costs for this drying were subtracted from the August bills, so that this expense has not been included in per gallon production costs.

If the profit from this drying operation were subtracted from production costs, Food and Energy would show a per gallon cost of approximately $1.60 for August instead of $1.68. It is expected by plant management that supplies of 190° ethanol will decline in the future as 190° plants either install drying capability or shut down.

Marketing its 200° ethanol has not been a problem at Food and Energy. Almost all output has been purchased by the By Rite Oil Company of Dearborn Heights, Michigan. In August, the net selling price to Food and Energy was $1.80 per gallon with By Rite picking up the ethanol at the plant.

Food and Energy has been incorporated as a Subchapter S Corporation. The main advantage of this type of incorporation are that the owners receive the same protection of limited liability afforded to owners and stockholders in regular corporations, but profits can be directly distributed to the owners without paying the corporate income tax. Losses and tax credit are also passed on to the individual investors in the corporation and may be deducted from personal income or income taxes in the case of tax credits.

One of the disadvantages of this type of corporation is that paid in equity capital cannot exceed $500,000. Since it is already at this limit, Food and Energy cannot seek more equity financing.

It should be noted that in determining capital costs per gallon for the plants in this study, the 10 percent investment tax credit and the additional 10 percent energy investment tax credit were not subtracted from the original investment. In both the Subchapter S Corporation at Food and Energy and the partnerships at Plant X and Mid States Energy, these credits are taken by the individual investors and must be considered by each investor individually in his calculations on investment profitability. This exclusion of tax credits is assumed throughout this report.

Plant X

Another midwestern plant from which data has been obtained has remained relatively unknown since it began production in August and chose to retain its anonymity. Cost data are in Table 2.

Plant X is also a low capital cost ($785,000) plant which produces 192^0 ethanol and sells WDG at approximately 65 percent moisture. It has been operating on a five day a week schedule and was producing around 72,000 gallons per month when visited in October. It would have a capacity of about 1,500,000 gallons per year if operated on a 24 hour a day, 360 day a year basis.

This plant has encountered a set of problems quite different from those of Food and Energy. It has a holding pond for waste water containing solubles, and does not reuse this water. According to workers at the plant, there have been no "bad batches" since start-up and the yield of 2.57 of 192 proof per bushel (or 2.47 on 200 proof basis) is quite high. They have found that letting the mash ferment for 72 hours instead of the more normal 40 to 48 hours increases yield slightly.

When the plant was built, the company which installed the stripper and rectifying columns offered a final column for distillation to 200^0 which employed benzene as an entrainer. It was felt that by the owners in the partnership that benzene, a carcinogenic agent, would be hazardous to handle and that its use might eventually be outlawed by the EPA. A unit to dry the ethanol with a method called the "salt process" was purchased for $105,000 from Process Design Association of Lincoln, Nebraska. In this process salts of potassium acetate and sodium acetate remove the water from the ethanol water azeotrope. Although the process appeared promising in small scale demonstrations, the unit installed at Plant X never functioned properly. During the best of times it was able to only dry 70 gallons per hour, well below the output of 150 to 180 gallons per hour from the rectifier. Eventually, after much experimentation, it was disconnected and hauled to a storage area behind the plant. Another report on the "salt process" from a plant in Nebraska has indicated problems with it there as well (Hill 1981).

The inability to produce 200° ethanol has, of course, been a major factor in the profit picture at Plant X, and the owners were investigating other methods for drying ethanol, especially use of molecular sieves. They were waiting to see how some of the commercially produced dehydrators employing sieves work for other producers. The ethanol is presently shipped out of state for drying at several other plants. With transport costs of from 6¢ to 8¢ per gallon, and a sales price of around $1.50, little or no profit could be made on the wet ethanol produced during October. Since profitability on 192 proof hydrated ethanol has been so low, additional loans would be necessary to purchase a new dehydration system.

When the plant does produce 200 proof, marketing the ethanol may be a problem. It is thought by the owners that most of the ethanol may have to be shipped out of state for sale, as no major local distributors have been found to purchase it. One large nearby distributor, who does purchase ethanol, had indicated he plans to continue purchasing ethanol shipped by rail tank car from ADM in Decatur, Illinois. In October, the ADM price in this area was only 3¢ per gallon above the $1.77 (f.o.b.) quote at Decatur. This situation illustrates the possibility that ADM, with its planned capacity of 237,000,000 gallons per year by June of 1982, may increasingly compete with smaller producers for ethanol sales.

Plant X has contracted with one large livestock producer to purchase all of the WDG it produces. This producer hauls the WDG from the plant in large steel refuse containers, and in October was paying 7¢ per pound on dry weight basis. Thus Plant X has avoided the marketing problems of Food and Energy, and the secret seems to be that it is better to be located near one large livestock producer who appreciates the feed value of WDG, than in the midst of many smaller livestock operations.

Unfortunately, Plant X has had considerable difficulty in recovering its distillers grains from the stillage. Its recovery rate of approximately 8 pounds (dry weight basis) per bushel is quite low. In general the lower the recovery rate, the lower the protein content of the WDG will be, as only the larger more fibrous particles are captured (White 1981).

The DG recovery system in use at Plant X is quite different from anything seen in other plants. It involves the stillage stream being forced through a cylindrically shaped screen, with liquids being squeezed out through the screen. Unfortunately this screen had been tearing several times a day, necessitating repairs and losing some distillers grains.

As a producer of 192° ethanol this plant was marginally profitable with corn under $2.50 in 1981. However, Plant X has operated at a rate closer to its capacity than the others in this report, even with its five day a week work schedule. The critical factor in this plant's profit picture has been the failure of the first ethanol drying system installed to live up to expectations. Selling 192° ethanol instead of 200° was costing this plant over $20,000 a month in revenues and an estimated $13,000 in profits (assuming a capital and operating cost for drying of 12¢ per gallon). The fact that the owners did not rush to buy a new drying system was partly due to lack of capital, but more importantly because they could not find a proven system readily available from manufacturers or other producers.

Mid States Energy Resources

One of the first Illinois producers of fuel ethanol to get into production was Mid States Energy of Lanark, Illinois which began producing in July of 1980. This plant, with a capital cost of $450,000 and an annual capacity of 625,000 gallons of 200° ethanol, was originally built to produce 190° ethanol. However, a dehydrator, employing molecular sieves, was installed in December of 1981.

During the last visit to the plant in November 1981, it was processing only five batches a week (250 bushels per batch yielding 650 gallons of 190^0) partly to maintain a supply of distillers grain to a nearby cattle feeder, as installation of the dehydrator was awaited. The dehydration unit purchased from Anhydrous Technology of Sugarland, Texas for $95,000 installed, has since been put into operation. According to the plant operator, Roger Hill, the unit produced 200^0 ethanol within ten minutes of startup, and has dried the 190^0 ethanol to 200^0 at a rate of 100 gallons per hour. This unit is quite different from the one in use at Food and Energy. The vapor from the rectifier goes directly into the dehydrator before being condensed, and the temperature necessary to regenerate the sieve material is 225^0F. At Food and Energy the vapor from the rectifier is condensed before it goes into the dehydrator, and temperatures of over 500^0F are necessary for regeneration. However, since the ethanol and water enter in liquid form, it is much easier to dry wet ethanol trucked in from other producers than it would be with the system at Mid States in which the vapor form enters the dehydrator.

Because of the recent change from a 190^0 to a 200^0 plant, four sets of figures are provided for Mid States, in Table 3. The first three columns are based on production costs for 190^0 and the last column is an estimated base case for 200^0 production based on operating figures from 190^0 production and recent estimates (Hill, 1982) of costs for drying to 200^0. Because of the low rate of production during the changeover period and the necessity to estimate some costs for 200^0 production, data from this plant have not been included in the sensitivity analyses.

Mid States Energy has been one of the more fortunate of the plants built to produce 190^0 ethanol. It has a highly efficient, low cost plant, with a capacity large enough to justify the purchase of a dehydration unit.

Its banker has been willing to forego principal repayments on its loan, and after difficulty, it was able to get a loan from private sources to pay for the dehydrator.

As a 190° producer, profitability was marginal. The 190° ethanol produced in November was sold to Food and Energy at a price of $1.45 per gallon. Shipping charges to Michigan were 10¢ per gallon, so net income was $1.35 per gallon which was about the cost of production with interest charges included. In other words, production was maintained at a level which paid interest on loans and provided a salary for the two employees, but little or no profit.

The profit picture at Mid States should improve considerably if the dehydration unit continues to live up to expectations. The plant gets high ethanol yields, has a good recovery system for wet distillers grains, and because of ease of operation, appears to be able to operate with smaller labor costs than the other plants studied.

A nearby feedlot operation with 8,000 cattle purchases most of the wet distillers grains (65 percent moisture) produced. The pricing system for WDG has been to sell it for 1¢ a pound (dry weight basis) under the quote for DDG of Grain Processing Corporation in Muscatine, Iowa, one of the nations largest producers of beverage alcohol.

Marketing the 200° output may prove to be the most difficult problem in the future at Mid States. Distributors have not yet been lined up to take all the expected increased production. This 200° ethanol will certainly be sold somewhere, but at what distance and transportation charges from the plant remains to be seen.

III. Sensitivity of Production Costs to Input Costs

The corn feedstock to produce a gallon of ethanol costs about $1.20. Since the going price for ethanol is $1.60-$1.70/gallon, it is easy to see that the corn price is an important, or "sensitive", input.

In this section, we systematize this argument and apply it to all inputs. At the outset, we distinguish between two concepts.

1. *Sensitivity:* the change in the cost divided by the change in the value of one input. This is usually evaluated for very small changes in inputs.
2. *Uncertainty:* the actual range over which a variable is expected to vary.

A short example may help. From the numbers above, a 1 percent change in the corn price will cause about a 1 percent $(1.20/1.60) \simeq 0.75$ percent change in the cost of ethanol; the sensitivity is 0.75. But, if we know that the corn price has an uncertainty of ± 10 percent (i.e., if it is reasonably certain that the actual corn price cannot be specified more carefully than this), then the uncertainty in the ethanol cost is about 7.5 percent.

In order to be specific we need the cost function for 200^0 ethanol production, which may be written as:

$$C = C_g/Y_{bu} - R_{bu}/Y_{bu}\,(S_{DGS}) + C_L/d + C_f + C_e + C_c + C_m + C_s + \frac{C_I\, r}{d\,\left(1-1/(1+r)^n\right)}$$

where:

C = total cost per gallon (\$/gal. 200^0 ethanol)

C_g = cost of corn (\$/bu.)

Y_{bu} = yield of 200^0 ethanol per bushel of corn (gal./bu.)

R_{bu} = recovery, in dry weight pounds, of distillers grains and solubles per bushel of corn processed (lbs./bu.)

S_{DGS} = sales price per pound (dry weight basis) of distillers grains and solubles recovered (\$/lb.)

C_L = cost of labor, total annual payroll for a labor force large enough to maintain production at full capacity (\$/gal. 200^0)

d = duty cycle. This is a fraction obtained by dividing actual production rate by total production capacity. For example, in a plant producing 600,000 gallons annually, but with a capacity to produce 1,200,000 gallons annually, d would be .5.

C_f = cost of input fuel (\$/gal. 200^0)

C_e = cost of electricity (\$/gal. 200^0)

C_c = cost of chemicals, enzymes, yeast, and water (\$/gal. 200^0)

C_m = cost of maintenance (\$/gal. 200^0)

C_s = cost of chemicals or other agents, such as molecular sieves, used in the distillation process (\$/gal. 200^0)

C_I = capital investment, per gallon of annual capacity, to construct the plant (\$/gal. 200^0). Investment tax credits have not been subtracted from total capital costs. In the plants studied, these credits were passed on to the individual investors or partners for deduction from personal income taxes. See text.

r = real rate of interest (per year).

n = expected plant lifetime, in years. It is also the period of time over which capital costs have been amortized.

The factor $\frac{r}{1 - 1/(1+r)^n}$ is the capital recovery factor. It is the inverse of the present value interest factor of an annuity for n years at r rate of interest. The cost function for production of non 200^0 ethanol is the same, with the term "200^0" replaced in all terms by the proof of the ethanol being produced.

We have established base case estimates for cost of production in $/gal. for three fuel ethanol plants, based on operational data and the assumption that the plants operate at full capacity, have a ten year lifetime, and are charged a real rate of interest of 3 percent on the total capital cost of the plant, which is amortized over ten years.

Sensitivity analysis indicates how sensitive total cost per gallon is to a change in each of the input factors. If X_i represents an input factor, strict sensitivity may be defined as ${}^{X_i}/C\ {}^{\partial C}/\partial X_i$ i.e., the ratio of the relative change in C to an infinitesimal change in X_i. For finite changes in X_i we can approximate by using derivatives, or more exactly, by varying X_i by a certain percentage from the base case, while holding all other input factors constant, and calculating how large a percentage change this causes in C. This can be converted, as we have done in our graphs to actual dollar changes in C for various percentage changes in X_i, the input factors.

All of the input factors can be assumed independent, with the exception of C_g, cost of corn and S_{DGS}, sales price of recovered distillers grains and solubles, and R_{bu} and Y_{bu}. Although sales prices for distillers grains are influenced by prices for other agricultural products such as soybean meal, they have in the past generally risen as corn prices rose.

A regression line between the monthly average per bushel price of #2 yellow corn at Chicago and the monthly average price of DDG per pound at Cincinnati from October 1978 through April of 1981 [Feed Situation 1979-1981] gives a relationship of DDG price (\$/lb.) = .0158 corn price per bushel + \$.0248 (current \$). Since DDG is normally at 10 percent moisture, the right hand side of the equation can be divided by .9, giving a dry weight DDG price per pound of .0176 C_g + \$.0276. The producers in this study were selling wet distillers grains, and one might expect WDG to sell for less than DDG on a dry weight basis because of difficulties in handling and problems with spoilage. However, probably because of lower transportation costs and lack of middlemen, these fuel ethanol producers were able to sell their distillers grains at prices comparable on a dry weight basis to Cincinnati quotes for DDG. With corn at or near \$2.50, all the producers studied were selling their WDG (65 percent moisture) at a price of \$.07 per pound dry weight basis. The regression equation of dry weight DDG (\$/lb.) = .0176 C_g + \$.0276 gives a price of \$.0716/lb. (dry weight) with corn at \$2.50, which is within \$.0016 of the price actually received by producers when corn was within 5¢ of \$2.50/bu. For the sensitivity analysis, we could have considered C_g and S_{DGS} as independent variables, allowing C_g to rise without a rise in S_{DGS}. However, it seems more realistic to link prices of corn and distillers grains, and we have replaced S_{DGS} with (.0176 C_g + .026) in the cost function in the sensitivity analysis. It must be noted that we have changed the y intercept of our regression line from .0276 to .026 in order that the expression (.0176 C_g + .026) give an exact price of \$.07/lb. (dry weight) for distillers grains when corn is at \$2.50/bu. This change makes less than a \$.01 difference in any of our calculations of total cost, and allows the regression line to pass through a data point which was significant in the data collected from the plants--the 7¢/lb. (dry weight) sales price for DG with corn at or near \$2.50/bu. Because of this linkage, a price rise of \$1.00 a bushel for corn at Food and Energy (Y_{bu} = 2.35, R_{bu} = 13.5) would lead to a \$.32 rise in C instead of a \$.43 rise as would occur if C_g rose independently and S_{DGS} remained constant.

Other researchers [Meekhoff, Gill, Tyner, 1980] have assumed that three-fourths of the increase in corn prices will show up in DDG prices, i.e., a 100 percent price rise in corn will lead to a 75 percent price rise in DDG. Our linkage shows a slightly lower rise in DDG prices as corn prices rise, and a slightly lower decrease in DDG prices as corn prices decline. However, should fuel ethanol production greatly exceed current expectations (see Appendix B), neither relationship would hold, and DDG prices could change at a significantly different rate, relative to corn, than we have projected.

There is some relationship between R_{bu} and Y_{bu} as well. As yield of ethanol decreases, recovery of DGS should increase--up to the point where when Y_{bu} = 0, we could have a recovery of 56 pounds of mashed corn. The linkage is weak for reasonable values of the two variables, and we treat them as independent. The factors which, when combined, give us our net cost of corn per gallon, $C_g/Y_{bu} - R_{bu}/Y_{bu}$ (0.176 C_g + \$.026), gives a reasonable estimate of net corn cost per gallon only for values of Y_{bu} which are above 2.0 gal./bu.

Dividing cost of labor per gallon, C_L, by d in the cost function implies that labor costs per gallon would double if the plant operated at half its capacity, or conversely that labor costs per gallon would be cut in half if a plant went from operation at half of capacity to full capacity. In other words, a constant labor force is assumed. It could be argued that the labor force would be cut with a drop in production. However, one of the noticeable features of the six plants visited gathering data for this report was that even at low production rates, there were usually enough employees on hand to maintain full production. Part of the reason for this lies in the nature of ethanol production. With steam generation and a flow of materials under various pressures, someone must be on hand at all times during operation, whether he is producing a lot or a little. Also, operators seem to like to have at least two people working per shift in case emergencies arise.

Figures 1 and 2 show the sensitivity of total per gallon costs for a 200^{0} and a 192^{0} fuel ethanol plant, based on variations in input factors from the base cases presented earlier.

IV. Uncertainty Analysis

Uncertainty analysis is really based on common sense. An input whose cost is uncertain can have a large influence on the uncertainty of the total cost of production because 1) it is an important input factor; the cost is sensitive to it, 2) its uncertainty is large, or both. In fuel ethanol production, corn price would be an example of an input factor which is both important and highly uncertain.

An approximate measure of the expected uncertainty for an input X_i can be obtained by multiplying the percentage change in the cost (C) caused by a 1 percent change in input i (X_i) by the expected range of uncertainty in X_i. Positive uncertainty $\Delta X_i^{+}/X_i$ and negative uncertainty $\Delta X_i^{-}/X_i$ must be estimated with a stated probability that cost of input X_i will remain in that range. For this study we have used a probability of .7 for our estimates. For example, for corn it is assumed that there is a 70 percent probability that corn prices in 1981 dollars, will range between \$5.00$\left(\Delta X_i^{+}/X_i = {}^{2.50}/2.50 = 1,\right)$ a 100 percent increase from the base case, and \$2.25$\left(\Delta X_i^{-}/X_i = {}^{.25}/2.50 = .10,\right)$ a 10 percent decrease from the base case.

Because these estimates are for the ten year expected lifetime of the plants, a 70 percent probability that input prices will be in the ranges we have specified seems reasonable. It is an arbitrary choice and its use is intended only to give the reader a general idea of the chances that various imputs will be in the specified ranges.

Before presentation of a table summarizing the expected positive and negative uncertainties, for the various input factors, a brief rationale for the selection of these expected ranges is given.

Prices for corn paid at East Central Illinois terminals for the crop years 1959 to 1978 have been compiled in 1972 dollars [Good 1980]. By using the GNP implicit price deflator for the third quarter of 1981 of 195.44 (1972=100),[Survey of Current Business 1981], corn prices in third quarter 1981 dollars have been computed.

They are:

	$/bu.		$/bu.
1959	3.09	1969	2.69
1960	2.89	1970	2.89
1961	2.89	1971	2.25
1962	3.15	1972	3.40
1963	3.13	1973	4.86
1964	3.25	1974	4.70
1965	3.21	1975	3.91
1966	3.19	1976	3.07
1967	2.52	1977	2.85
1968	2.66	1978	2.97

The mean price for this period was $3.18 (third quarter 1981 $) and the standard deviation was $.6472. If we assume corn prices fall into the normal bell shaped curve, we can calculate that 70 percent of yearly average corn prices should fall between $3.85 and $2.51 per bu. In actuality, 80 percent of the prices were within this range during the twenty year period studied. However, it should be noted that corn prices became more erratic in the 1970's as government farm programs were dropped and prices were allowed to fluctuate without government interference. A more accurate indicator of future variations in prices may be obtained by using the prices from 1969 to 1978. The mean of these prices is $3.36 per bushel, and the standard deviation is $.87. Again assuming a normal distribution, we would expect to find 70 percent of the corn prices to be between $4.26 and $2.46 for these years. In actuality 70 percent of the prices were within this range. The U.S. Government loan program loaned farmers \$2.40 per bushel of corn in 1981 and will loan \$2.55 per bushel in 1982. Should this program continue in its present form, it would set an effective floor on corn prices. However, if a set-aside provision is introduced and farmers must join the set-aside program to qualify for the loan program, the floor might disappear if large numbers of farmers do not join the program. Because of a belief that price volatility will continue to increase, with a bias on the upside, we have assumed a 70 percent probability that corn prices will be between \$5.00 and \$2.25 a bushel (1981 \$) during the plants lifetime.

Another input cost which could vary significantly in real terms is that of fuel, especially natural gas and natural gas derivatives such as propane. Prices for newly discovered natural gas are scheduled to be decontrolled in 1985, but there is a strong possibility that they may be decontrolled before that, with a windfall profits tax on producers. With total decontrol, natural gas prices could rise to the point where natural gas sells at a price equivalent to oil on a BTU content basis at the point of consumption. Should this happen, the price of natural gas would be approximately \$5.20 per 1000 feet^3 (1981 \$) when residual fuel oil is at the present \$31.00 per barrel, (wholesale average for 1981) [Monthly Energy Review]. For Food and Energy, a price of \$5.20 per 1000 feet^3 would be a 47 percent price rise from the present price of \$3.53 per 1000 feet^3. For Mid States Energy it would be a 27 percent increase from present rates. These rises could occur merely from a change in the way natural gas is priced, even if crude oil prices remained constant in real terms.

The U.S. Department of Energy [Annual Report to Congress, 1980] does not expect natural gas prices to reach a BTU equivalent price with petroleum by 1990, but it does project real price rises for oil. Under its "middle" oil price rise scenario, with oil rising from \$31 a barrel in 1980 to \$41 in 1990 (1979 $), it projects a price rise in natural gas for industrial users from $2.00 per million BTU in 1980 to $4.37 per million BTU in 1990 (1979 $), a 118.5 percent increase. In our uncertainty analysis we assume a 70 percent probability that natural gas prices will range from the present price up to a 100 percent increase in real terms during the plants lifetime. Under the same oil price rise scenario, the Department of Energy also projects a real price rise for electricity of 21 percent during the 1980's. In light of the steep rate increases some utilities, especially those with large nuclear construction projects, have made in the past year, the 21 percent real price rise estimate for the ten year period could be on the low side. We assume a 70 percent probability that the cost of electricity will be between the present price and a price 25 percent greater in real terms, during the plants lifetime.

Other production costs such as labor, chemicals, yeasts and enzymes, maintenance and sieve material are not expected to vary greatly in real terms over the next ten years.

Using the hourly earnings indexes for production or nonsupervisory workers on private nonfarm payrolls [Handbook of Labor Statistics,1980], an analysis of the data from 1964 to 1979 for the manufacturing sector indicates that the largest real increase in hourly earnings in any decade was 10.0 percent from 1966 to 1976. There were no declines in any ten year period, and the average real increase was 8.5 percent for a ten year period.

Many of the workers in the ethanol plants studied were farmers, supplementing their farm income. Real wages for these workers may be expected to lag real wage increases in other industries; especially heavily unionized ones. There has been a general trend toward lower real wage increases during the past five years, and we assume, with our 70 percent probability, that real wages in the fuel ethanol plants will be between the present rate and a 5 percent increase in real terms over the plants lifetime.

Over the ten year period, 1970-1979, non-durable goods prices rose approximately 3 percent more than the rate of inflation, or 3 percent in real terms [Statistical Abstract of the U.S.,1980]. For our uncertainty analysis, we have assumed a 70 percent probability that real prices of chemicals, yeasts, enzymes, and molecular sieves will not decline and will rise by 3 percent during the 1980's in real terms. Cost of maintenance, fixed at 5 percent of total capital cost annually for the base case, could be substantially higher than this. The abrasiveness of the stillage and mash as they flow through pipes and pumps has surprised some producers. One who had been replacing pumps frequently spoke of getting the same kind of pumps used for gravel or sand. Considering that many of the prices of equipment used in the plants studied had not been tested for long periods of time in ethanol production, it seems quite possible (with a 70 percent probability) that maintenance costs could double in real terms from base case figures.

Expected range of uncertainty in the factors R_{bu} and Y_{bu} depends to some extent on what these factors were when the base case was established. For example, with a R_{bu} of 8 pounds at Plant X, we would expect a high probability that R_{bu} could increase toward a more normal R_{bu} of 11 to 12 pounds, while at Food and Energy with a recovery of 13.5 pounds per bushel, with heavy water reuse, we might expect some decline in R_{bu} if heavy water reuse is discontinued. Likewise, Y_{bu} may be expected to move toward 2.5 gallons (200^0 basis)/bu. over the plants lifetime, so that a plant such as Food and Energy, with a Y_{bu} of 2.35 gallons (200^0 basis)/bu. would have an expected increase in yield, while Plant X with Y_{bu} of 2.48 (200^0 basis)/bu. would be expected to remain the same. For the uncertainty analysis, we assume a 70 percent probability that a given plant will achieve a R_{bu} of 12 pounds (dry weight basis) and a Y_{bu} of 2.5 gallons 200^0/bu. during its lifetime.

Estimating expected range of uncertainty in d is quite subjective. The plants observed were still in what may be considered the start up phase, and it is difficult to predict at what percent of capacity they will operate over their lifetime. Food and Energy expected to increase production in October and November of 1981 from the August figure of 49,355 gallons. This did not occur, partly because of an implosion in a fermentation tank which was left closed with steam inside after cleaning,and the plant continued to operate at less than 50 percent of capacity during these months. Plant X was operating at 57 percent of capacity with a five day a week schedule, which would have been 80 percent of capacity if operated 7 days a week at the same rate of production. Base case figures were calculated with the assumption that the plants operated at full capacity. However, one of the characteristics of the low capital cost plants studied seems to be that it is more difficult for them to operate at stated full capacity than for higher cost plants. Therefore, we assume, with 70 percent probability, that the plants will operate at between 60 percent of capacity (d =.6) and capacity (d = 1) during their lifetimes.

Capital cost has been fixed for the individual plants studied and will not vary. We have set the factors r = 3 percent and n = 10 to calculate base case figures. The real interest rate r could have been set at from 2 percent to 6 percent with some support for choices within this range, so we will assume a 70 percent probability that r will be in this range during the plants lifetime. The number of years over which the plants capital cost is amortized, n has been set in the base case to be equal the expected lifetimes of the plants, ten years. Should the plants have shorter or longer lifetimes, n would vary. We think there is a 70 percent probability that plant lifetimes will be between 8 and 12 years.

Table 4 lists the expected uncertainties for the various inputs, X_i, in the cost function for Food and Energy, Inc. We see that the inputs which affect uncertainty in C the most are C_g, C_f, and d. Total cost C, is quite sensitive to changes in R_{bu} and Y_{bu} as indicated in the first column. However the expected range of fractional uncertainty, the probability of a change in R_{bu} or Y_{bu} from the base case, is small and expected uncertainties for R_{bu} and Y_{bu} are therefore small relative to expected uncertainties in C_g, C_f, and d.

An estimate of positive uncertainty[1/] may be made by taking:

$$\Delta C^{+}/C = \sqrt{\sum_{+} \left({}^{\partial C}/\partial X_i \quad {}^{\Delta X_i}/C\right)^2},$$

where $\sum_{+}$ denotes a sum over all ΔX_i which make ${}^{\partial C}/\partial X_i \quad {}^{\Delta X_i}/C$ positive

Negative uncertainty[1/] may be estimated using the formula:

$$\Delta C^{-}/C = \sqrt{\sum_{-} \left({}^{\partial C}/\partial X_i \quad {}^{\Delta X_i}/C\right)^2},$$

where $\sum_{-}$ denotes a sum over all ΔX_i which make ${}^{\partial C}/\partial X_i \quad {}^{\Delta X_i}/C$ negative

Using the data from Food and Energy, Incorporated in Table 1, we calculate positive uncertainty to be .610 and negative uncertainty to be .066. Applying this to the base case value of $1.37/gal., we can state that we believe there is a 70 percent probability that total production costs at Food and Energy, Incorporated will range between $1.28/gal. and $2.21/gal. (1981 $) over the estimated ten year lifetime of the plant.

[1/] *These expressions are approximations to account for the fact that the expected range of uncertainty of many of the variables is asymetric about the mean value. In general ΔC^{+} and ΔC^{-} would be slightly closer to the same value if calculated exactly, than by the approximation used here. Given the various uncertainties in our method, we feel that the approximation is justified.*

In our calculations for Food and Energy, we have assumed C_I, capital investment per annual gallon would not vary from the base case, since the plant has already been constructed and capital costs are known. For someone else considering building such a plant, C_I could vary, and the expected fractional uncertainty from C_I would have an effect on calculations of positive and negative uncertainty. If we assume that there is a 70 percent probability that C_I will be between \$.50 and \$.90 for construction of this type of 200° fuel ethanol plant. $\Delta C_I^+/C_I$ would be .27 and $\Delta C_I^-/C_I$ would be .30. Expected positive uncertainty for C_I would equal .06 X .27 = .0162 and expected negative uncertainty in C_I would be .06 X .30 = .018. Using these new values, along with the others in Table 1 used in our previous calculations of positive and negative uncertainty, we find that the positive uncertainty, with C_I varied is still .61 and the negative uncertainty is .068. Again the expected range is between \$1.28/gal. and \$2.21/gal. Varying C_I has caused almost no change in our uncertainties, mainly because total cost per gallon, C, is relatively insensitive to changes in C_I when plant lifetime is held constant at ten years. Of course, as plant lifetime decreases, C becomes more sensitive to changes in C_I.

V. Economic Viability

The economic viability of these plants may be measured in several ways. One would be to do a net present value analysis, using various scenarios with differing input and output prices. Another method would be to compute levelized costs of production and then subject these to uncertainty analysis, estimating the probability that profitable conditions will occur. We will use the latter method, since it more easily allows comparision with the costs of competing fuels.

Any projections on the financial returns from the plants studied or the "model" plant described later, are of course dependent to a large extent on fuel ethanol prices. While our purpose here has been to compute costs of production, it is necessary to comment on the selling price of the product. Probably the most surprising factor for those who built fuel ethanol plants in 1980 or 1981, has been the moderation, and even decline recently in real terms, in wholesale gasoline prices. Fuel ethanol prices declined from $1.80 (f.o.b. ADM, Decatur, IL) to $1.70 in December of 1981. The inability to get the expected higher output prices when plants came on stream in 1981 has caused what may be called the "start up syndrome" in several plants.

Most of the initial capital for these plants was exhausted during construction. When production began, it became evident that additional capital improvements were necessary for increased efficiency. The lower than projected ethanol prices meant that there was not enough cash flow to pay for these improvements. Therefore, the producer was left in the position of having an inefficient plant, needing improvements he could not afford over the plants' lifetimes. In addition, there is the possibility that increased competition for the midwest ethanol market may lead to a decline in price in the midwest. This possibility affects, to some extent, the possibility of a real price rise in gasoline which would otherwise raise ethanol prices.

The energy price outlook today is markedly different from that in effect when the plants studied were planned. At that time it was frequently projected that 200^0 ethanol prices would be over $2.00 a gallon in 1981. We have no crystal ball for energy price projections, but the most reasonable course would seem to be to take the word of the one person who is in a position not only to predict future oil prices, but also to control them to some extent, Sheik Yamani of Saudi Arabia. In a recent pronouncement [Wall Street Journal, January 19, 1981] he reiterated his belief that the inflation adjusted price of oil will remain stagnant during the 1980's and not begin increasing until the 1990's. Should Sheik Yamani and the Saudi Royal Family remain in power, and retain their present oil pricing policies, without supply disruptions caused by war or sabotage, it seems quite possible that the Sheik's oil price scenario will be accurate.

For ethanol plants located in the Midwest, the present output price of $1.70 (f.o.b. ADM, Decatur, IL) would seem to be the most reasonable one to use as a basis for estimating plant profitability. Should there be no real price increase in oil over the next decade, this price may also remain constant in real terms over the plants' lifetimes. In addition, there is the possibility that increased competition for the Midwest ethanol market may lead to a decline in price in the Midwest. This possibility lessens, to some extent, the probability of a real price rise for ethanol even when gasoline prices do rise.

The yearly 1¢ decline in the state tax exemption for gasohol as written into the Michigan and Illinois laws also may mitigate price rises. Production of U.S. fuel ethanol is concentrated in the Midwest. In California, the largest state gasoline market in the U.S., there are only two major producers of fuel ethanol who produce a total of 5,000,000 gallons annually from culled fruit. California used approximately 18 million gallons of 200° fuel ethanol for gasohol in 1981 [Kerstetter, 1982], so "imports" were approximately 15 million gallons. However, producers such as those in this study who cannot ship by rail tank car, have no access to this market, and may face competition in the Midwest which would moderate the potential for price increases.

If we somewhat arbitrarily assume a real output price of $1.70 per gallon of 200° ethanol (1981 $) during the plants' lifetime, in order to facilitate our analysis, what is the likely profit picture of the plants' studied with this output price? Since our base case figures assumed no inflation, and we assume no inflation in the output price of$1.70, these figures may be compared. For Food and Energy, the base case production cost per gallon was $1.37. Thus a profit of $.33 per gallon would be expected for each of the gallons produced under the conditions and input prices stipulated in the base case.

We have seen from our sensitivty and uncertainty analysis that there are really just three major factors which account for over 85 percent of the uncertainty in production costs. They are the price of corn, the price of fuel (natural gas) and the fraction of design capacity at which the plant runs, d. Since the base case was established with d = 1, any uncertainty in d would be for a decline in d, and a rise in production costs. We have also assumed a zero probability that fuel costs will decline from the base case, so any change in C_f will also be an increase in production costs over the base case. With corn price the positive fractional uncertainty $(^{\Delta C}/C)^{+}$ is .59 while the negative fractional uncertainty is .06, reflecting the much greater likelihood that corn prices will rise from the base case figures, than decline--again increasing production costs.

The essential question to answer for a measure of profitability is what changes in these three factors or combination of changes, could cause production costs to exceed some reference level such as $1.70 a gallon at Food and Energy; and how likely are these changes to occur? From Table 5 it can be seen that with input fuel and other input prices held constant, production costs begin to exceed $1.70 when corn is over $3.51, even with the plant operating at full capacity. Operating at .8 of capacity, the maximum corn price possible for production costs to remain below $1.70 is $3.30. At d=.6 it is $2.93.

We have speculated that natural gas prices could double in real terms during the plant's lifetime. For the base case at Food and Energy, natural gas cost was $.15 per gallon. Table 6 shows the maximum corn price possible while maintaining total cost per gallon below $1.70, for various combinations of d and C_f.

The operational data from the plants in this study must be considered as coming from the start up phase of operation. The base case projections we have made are an attempt to predict production costs after the start up phase, when production at full capacity is reached. The base case figures for these plants are quite similar, which may have been expected considering the similar construction costs per gallon for the plants. As mentioned earlier, all three plants bought used fermentation tanks which came from the same brewery. In two of the plants these tanks were also used as cookers. But apart from the tanks, all the major pieces of equipment such as strippers, rectifiers, DG recovery systems, dehydrators and heat exchangers, were of different design. In light of this, the closeness in per gallon costs is somewhat surprising.

The economic viability of the type of plants included in this study may best be estimated by making a new base case, in which the best features from the three plants are included. One would expect someone building a new plant to do this, and also for the plants in the study to be modified eventually in this way. This "best" plant would have the stripper and rectifier from Plant X (manufactured by L. & A. Engineering, Turlock, CA) which can separate fusel oils; the molecular sieve dehydration unit designed by Food and Energy, which seems the most proven at this time; the DG recovery system of Food and Energy, the waste water disposal system of Plant X, the automatic controls and heat exchangers in use at Mid States, and of course the ubiquitous used fermentation tanks.

This plant would have a capacity of 1,500,000 gal./yr. a Y_{bu} of 2.5, a R_{bu} of 12 pounds, and could be built for approximately $1,000,000. The base case figures for such a plant, with corn at $2.50, and the $1,000,000 capital cost considered debt at a 3 percent real rate of interest amortized over 10 years, are estimated below.

	Base Case
Corn	.66
Fuel (natural gas 3.53)	.15
Electricity	.06
Chemicals	.13
Maintenance	.03
Sieve Mat	.03
Labor	.16
Capital	.08
	$1.30

As can be seen from a comparison with the base case figures from Food and Energy, the model plant has operational characteristics very similar to Food and Energy. It is basically a Food and Energy plant with increased capacity, increased automation to allow production at this new capacity without increasing the labor force, and a waste water disposal system so that process water does not have to be reused. Without water reuse, chemical costs should decline, yield of ethanol increase, and recovery of DGS decline. The net effect of increased Y_{bu} and decreased R_{bu} is that C_g remains unchanged.

The base case drying figure for the model plant could have been lowered by about $.04/gal. if the molecular sieve dehydration unit at Mid States Energy had been included as the drying unit. However, this unit has not been in operation long enough to be included with any great degree of confidence.

We can also carry out some sensitivity analysis of the "model" plant. Estimated costs of production for 200^0 ethanol at various corn prices and rates of production with all other inputs held constant, is summarized in Table 7.

For this model plant, production costs exceed $1.70/gal. when corn is over $3.75 and d = 1, when corn is over $3.56 and d=0.8, and when corn is over $3.24 and d= 0.6.

If fuel prices are varied, and inputs other than d and C_g are held constant, Table 8 shows maximum corn prices possible while maintaining total cost per gallon below $1.70.

By varying the three major factors most likely to cause changes in total production costs from the base case in the model plant, we see that the corn price range, which allows production at under $1.70/gal., has been extended by between $.34/bu. and $.30/bu. (depending on scenario) over the range allowed using the base case from Food and Energy.

Various profit (or loss) scenarios can be drawn from the above tables and the assumption of a $1.70/gal. real output price during the plants lifetime. If one assumes that corn prices in the 1980's will approximate the $3.36 mean price (1981 $) of corn in the 1970's, that plants will operate at .8 of capacity, and that natural gas prices will rise by 33 percent in real terms (to .20/gal.), Food and Energy would be unprofitable, and the model plant marginally profitable.

From observations of plant operations, an operating rate of 0.8 seems most likely for them over their lifetimes. Since none of the plants in this study had operated over 0.6 of capacity, after several months of start up time, the 0.8 figure may seem optimistic. But operational rates should improve once the bugs are worked out.

With an output price of $1.70/gal. one would have to conclude that fuel ethanol plants of this type are an extremely risky venture. We have not performed more interpretation of the data from Plant X, the 192^0 producer, because production of less than 200^0, even with corn under $2.50, is only marginally profitable because of the low output prices received. At the present time (January 1981), with corn under $2.50, the 200^0 producers such as Food and Energy and Mid States Energy should be quite profitable if they can produce near their stated capacities.

If one chooses to accept the Department of Energy's middle or high price projections for world oil prices from 1980 to 1990, [Annual Report to Congress, 1980] higher output prices would be used in calculations on profitability. The DOE middle price rise scenario projects a 32 percent real increase in oil prices for this decade, and the high price rise scenario projects a 58 percent rise in oil prices in real terms. This would lead to higher output prices than the $1.70 we have used. We repeat that the reader can calculate costs of production for his own favorite set of input prices from Equation (1).

In addition, it must again be noted that we have not subtracted the energy investment or regular investment tax credits from our cost of production calculations. These credits total somewhat less than 20 percent of the total capital investment, as certain parts of the plant do not qualify for the energy investment tax credit. Boilers fueled by oil, natural gas, coal, or any derivative of these fuels do not at present qualify for the energy investment tax credit.

VI. Summary and Conclusions

Based on actual operational data, base case estimates of costs of production have been calculated for three operating fuel ethanol plants. These plants had many characteristics in common, especially their low capital cost. Partly because of the low capital costs, one of the main problems in these plants has been rising additional capital for the installation of equipment to dry 190^0ethanol to the 200^0necessary for blending with gasoline. Dehydrators using molecular sieves seem to be the best answer to this problem, and in two of the three plants studied, production costs were not very sensitive to drying costs--once properly designed dehydrators were in place. Sensitivity to total capital cost, C_I, was also low with the assumption of a 10 year operating lifetime. However, should the economic conditions which allow profitable operation of these plants be much shorter than this, total cost per gallon would be more sensitive to capital costs. If, for example, the era of fuel ethanol production from corn lasted only a few more years, capital costs per gallon would rise sharply, but high capital cost plants would be more dramatically affected than those with low capital costs and a shorter payback period.

Because Food and Energy, Inc. was the only plant with an adequate operating history as a 200° ethanol producer, most of the sensitivity and uncertainty analysis was based on data from this plant. Total production cost per gallon was found to be most sensitive to changes in C_g (cost of corn \$/bu.) Y_{bu} (yield of 200° ethanol/bu.) and R_{bu} (recovery of distillers grains/bu.).

Y_{bu} and R_{bu} are largely determined by the technology in place or readily available, and are not expected to change much from base case values. In using base case data for economic projections it is important to pinpoint those production costs or variables which are likely to change significantly and in which this change will have a significant effect on total cost. The three factors which were found most likely to cause future variation in base case total cost were C_g, C_f (cost of fuel) and d (annual production/annual capacity). Since these three variables account for over 85 percent of the expected fractional uncertainty in total cost, one can get a reasonable estimate of total production costs per gallon, under different input price scenarios, by varying just these three factors. We have shown estimated total production costs per gallon for both Food and Energy, Inc. and a model plant for different values of C_g and d, as well as the maximum price possible to pay for corn and keep total production cost under \$1.70 a gallon with different values of d and C_f.

Reasonable price scenarios for both input and output prices can be created, some of which show these plants to be profitable ventures; some, unprofitable. Compared to many business ventures the risk is extremely high. It is hoped that the data and analyses presented in this report has enabled the reader to more accurately evaluate the economic viability of the particular category of fuel ethanol plant examined.

Works Cited

Annual Report to Congress, Volume III, 1980. U.S. Department of Energy, Energy Information Administration. Washington, D.C.: U.S. Government Printing Office.

Berger, Larry L., 1981. University of Illinois, Urbana, IL: Personal Communication.

Chambers, Robert S., 1981. ACR Process Corporation. Champaign, IL: Personal Communication.

Conrad Industries, 1981. Conrad Industries Have Perfected A Process for Making Anhydrous Alcohol. Bonaparte, IA: Conrad Industries Corporation.

Dovring, Folke, Robert Herendeen, Randall Plant, and Mary Anne Ross. "Fuel Alcohol From Grain: Energy and Dollar Balances of Small Ethanol Distilleries and Their Economies of Size and Scale." University of Illinois, Illinois Agricultural Economics Staff Paper No. 80 E-151, ERG Document No. 313, Energy Research Group, Urbana, IL, December 1980.

Feed Situation, 1979-81. Washington, D.C.: U.S. Government Printing Office.

Fuel From Farms, 1980. Golden, CO: Solar Energy Research Institute, SERI/SP 451-519.

Gasohol U.S.A., December 1979. "Water Separability Trials." Kansas City, MO: Gasohol U.S.A.

Good, Hieronymous, Hinton, 1980. Price Forecasting and Sales Management. University of Illinois, Urbana-Champaign, IL.

Handbook of Labor Statistics, 1980. U.S. Department of Labor, Bureau of Labor Statistics, Washington, D.C.: U.S. Government Printing Office.

Hertzmark, Ray, Parvin, 1980. The Agricultural Sector Impacts of Making Ethanol From Grain. Golden, CO: Solar Research Institute, SERI/TR 352-554.

Hill, Roger, 1981. Lanark, IL: Personal Communication.

Keinholz, Eldon, September 1980. "Stillage, What It Is, How It Fits in Livestock Feeding." Farm Energy, Vol. 1, No. 8, 1980.

Meekhof, Gill, Tyner, 1980. Gasohol: Prospects and Implications. Agricultural Economic Report No. 458. Washington, D.C.: U.S. Government Printing Office.

Monthly Energy Review, March 1982, DOE/EIA-0035(82/03), Energy Information Administration, U.S. Department of Energy, Washington, D.C.

Noyes Data Corporation, 1979. Ethyl Alcohol Production and Use As A Motor Fuel. Park Ridge, NJ: Noyes Data Corporation.

Saunders, Lewis, 1981. Food and Energy, Inc. Litchfield, MI: Personal Communication.

Statistical Abstract of the U.S., 1980. U.S. Bureau of the Census, Washington, D.C.: U.S. Government Printing Office.

Survey of Current Business, November 1981. U.S. Office of Business Economics, National Income Division. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Agriculture, 1980. Small-Scale Fuel Alcohol Production. Washington, D.C.: U.S. Government Printing Office.

White, Jack, 1981. Whiteflame Distillery. Van Buren, AR: Personal Communication.

W.R. Grace, 1981. "Ethanol Drying Using Davison Molecular Sieves." Baltimore, MD: Davison Chemical Division, W.R. Grace Company.

Appendix A

Molecular Sieve Technology

Probably the most critical production problem facing smaller scale fuel ethanol producers has been how to dry ethanol from 190° to 200°. Most of the ethanol produced in the past from fermentation of grains has been for beverage or industrial use, and 190° is all that is required in most cases. Until the advent of the fuel ethanol movement, there was just no necessity for drying large quantities of fermentation ethanol to 200°.

The proven benzene technique and the apparently successful process using gasoline as an entrainer, both require capital costs which are too high for many producers with capacities below 2,000,000 gal./yr. The use of dehydrators containing molecular sieves seems to be the most promising solution to this problem.

According to W.R. Grace, a leading manufacturer of molecular sieves, they are "crystalline metal aluminosilicates with a three-dimensional interconnecting network structure of silica and alumina tetrahedra." The actual sieve material looks like small BBs made of light colored clay.

There are various types of molecular sieves, but the basic operational principle is the same. The micropores in the sieve material are large enough to absorb the water molecule, but small enough to exclude the larger ethanol molecule.

A very simple dehydration unit would be a tank filled with molecular sieves. Wet ethanol would be allowed to sit in the tank until the water was adsorbed, then the dry ethanol drawn off. The sieves would then be regenerated by passing hot gases through them to drive off the water. In practice, designs are much more complex and there is usually a flow of ethanol through them.

There can be no doubt that this process works. It has been employed in industry for years, to dry small quantities of relatively clean ethanol, and it has been used successfully by Food and Energy and other fuel ethanol producers. One question mark though is how long the sieve material will last. Fuel ethanol contains fusel oils and other compounds, which if not removed before entering the dehydrator, may cause the sieve material to lose its ability to absorb water. This has already happened in two known instances, once within three months of the start of operation. One school of throught is that this problem can be alleviated by proper design of the dehydrator. Another is that fouling of the sieve material will alwasy be a problem, no matter what the design, because of the non-ethanol compounds contained in the fermentation product which cannot be completely removed before it enters the dehydrator, except at great expense. Only after years of opeation of the variously designed dehydrator using molecular sieves to dry fuel ethanol will the answer be known. Meanwhile, the effect of sieve material lifetime on fuel ethanol production costs can be estimated. W.R. Grace recommends use of 28,000 lbs. of sieve material for a drying capacity of 5,000 gallons a day. Food and Energy has attained a 5,000 per day drying capacity using 18,900 pounds of sieves; and the unit at Mid States Energy needs only 3,000 pounds for its 2,400 gallon per day output. Molecular sieves (type 3A) from W.R. Grace sold in 1981 for $1.75 per pound when purchased in bulk. Using the higher W.R Grace estimate of sieves needed for attaining a 5,000 gallon per day drying capacity, we arrive at an estimated cost of sieve material of $.027 per gallon dried if the sieve material lasts one year. As is generally expected, the following chart gives per gallon drying costs for molecular sieves with varying lifetimes.

Useful lifetime of molecular sieves in months	Estimated cost of sieves per gallon dried
2	$.162
4	.081
6	.054
8	.041
10	.032
12	.027
18	.018
24	.014

Energy costs for operation of the dehydrators using molecular sieves at Food and Energy have been about 1.7¢ per gallon dried for electricity (.27 Kwh/gal.) and 4.7¢ per gallon for natural gas (13 cu. ft./gal.). Preliminary estimates from the dehydrator in use at Mid States Energy are that energy cost will be under 3¢ per gallon dried. The designer of the unit at Mid States, Anhydrous Technology, estimates that its sieve material will last 5 to 7 years. However, no dehydrator employing molecular sieves has been in operation this length of time drying fuel ethanol.

Appendix B

Illinois Fuel Ethanol Production

Besides the four fuel ethanol plants mentioned earlier, and the Mid States Energy facility which has been described, Illinois has an interesting variety of plants in operation or due to come on stream in 1982.

There are four plants manufactured by Agri-Stills located in Kankakee, Indianola, Ottawa and Springfield. These plants operated sporadically in 1981, at times using unconventional feedstocks such as candy or cereal factory wastes. The plant in Ottawa has added additional equipment to the original 250,000 gal./yr. plant and expanded capacity. On each of three visits to the plant there was some new piece of equipment, including a dehydrator using molecular sieves. Costs from this plant were not included in this report because of the constantly changing conditions at the plant, but it should be ready for sustained operation in 1982 as a small but relatively "complete" plant.

Evan Leefer's "energy farm" in Carlinville has attracted a great deal of attention because of its use of anairobic digesters to produce methane gas from cattle manure. This gas is used to operate the ethanol production facilities, and the cattle are fed the stillage from the plant. The methane gas production system has worked well, but the ethanol plant has been in production sporadically due to mechanical problems and lack of a market for the lower proof ethanol output.

Southern Illinois Agro Food and Fuel of Metropolis has constructed a 700,000 gal./yr. plant, but operation has been very sporadic. There were problems with the original distillation equipment, and the lack of a market for the 190° ethanol output has kept this plant out of production for most of 1981.

Two especially interesting plants should be in operation in early 1982. They are the plants of Ag Mart near Monmouth and the vienna Correctional Institution at Vienna.

The 500,000 gal./yr. plant in Vienna plans complete utilization of plant by-products. Wet distillers grains, as a process by-product, will be fed to cattle at the Institution. CO_2 and heat from operations will be piped to a greenhouse, and a portion of plant stillage will be utilized as a food source for an aquaculture operation. Fresh water shrimp and golden shiners are to be produced, with some plant waste heat used for a hatchery pond.

Plastic fermentation tanks (6,000 gal. each) made of linear low density polyethelyne from Union Carbide will be used. Distillation to 200° is planned using pentane instead of benzene as an entrainer.

At Ag Mart, the all stainless steel components will allow the DDG to be marketed for human consumption. Markets in the Far East (Korea, Japan, China) are considered promising for this product. The 800,000 gal./yr. plant will use high moisture corn.[1/], which will be preserved by pumping CO_2 from the fermentation tanks into the storage bins. The ethanol will be dried with molecular sieve material from Reynolds Metals in a dehydrator with a design apparently differing significantly from others now in use.

At Farmers Energy, near East St. Louis, there are plans to utilize the distillers grains for dog food production. The dog food is already being produced with distillers grains from other sources, but the planned

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[1/] Several other producers have experienced difficulties in using high moisture corn. It is difficult to grind finely, and the larger particles have stopped up stripper columns.

and partially completed 3,000,000 gal./yr. plant is not due for operation until June 1982 according to recent projections. One operational feature of this plant, which distinguishes it from others studied, is the planned separation of the distillers grains from the mash after liquefaction, but prior to saccarification. Distillation to 200^0 is again planned with the use of pentane as an entrainer, instead of the more widely proven benzene technique.

Appendix C

National Fuel Ethanol Production

The effects of a large fuel ethanol program on corn and by-product prices, as well as soil erosion factors have not been taken into account in the analysis of production costs in this paper. So far the effects appear to be negligible, and at the rates of production projected for the foreseeable future, there should be little impact. The effect of increased production during 1982 is more likely to be on fuel ethanol prices than in feedstock costs.

In a study published in 1980, Hertzmark, Ray, and Pervin analyzed the impact fuel ethanol production would have on the agricultural sector. Using the POLYSIM model developed at Oklahoma State University, they projected the changes in corn, DDG, gluten meal and other agricultural product prices which might be caused by fuel ethanol production at varying rates. In 1981 fuel ethanol production is estimated at 130 million gallons.

If we take a relatively optimistic outlook for 1982 production of 280 million gallons, and 1983 production of 350 million gallons, the model shows the following differences in projected prices, in current dollars, caused by this production:

Table C-1

50% of by-product is DDG, 50% gluten feed & gluten meal	Base line case 1982, no fuel ethanol production	Simulation for 1982, 280 mil. gal. fuel ethanol produced	Base line case 1983, no fuel ethanol production	Simulation for 1983, 350 mil. gal. fuel ethanol produced
Corn	$ 2.448/bu.	$ 2.483/bu.	$ 2.469/bu.	$ 2.510/bu.
DDG	$133.972/ton	$123.453/ton	$132.799/ton	$120.084/ton
Corn gluten meal	$120.466/ton	$111.478/ton	$119.411/ton	$108.547/ton
Soybeans	$ 7.011/bu.	$ 7.018/bu.	$ 7.050/bu.	$ 7.059/bu.
Soybean meal	$202.192/ton	$198.514/ton	$200.421/ton	$195.727/ton

At the time the Hertzmark study was made, it was fuel ethanol production capacity which was the limiting factor in fuel ethanol production. During 1982 it is likely that productive capacity will exceed the ability to market fuel ethanol, unless ethanol prices drop further or there is a sharp rise in gasoline prices.

Table C-2 gives the production capacities of major fuel ethanol plants expected to be producing 200^0 ethanol in 1982. All of these plants are either completely constructed and operating, or actually under construction.

Table C-2

Plant	Capacity gal./yr.	Wet or dry milling
ADM (3 plants)	Total 237,000,000	
Decatur, IL	to be reached in	wet
Cedar Rapids, IA	June, 1982	wet
Peoria, IL		dry
Pekin Energy	Present	
Pekin, IL	60,000,000	wet
South Point Ethanol	Fall, 1982	
South Point, OH	60,000,000	dry
A. E. Staley	Fall, 1982	
London, TN	40,000,000	wet
Kentucky Agricultural Energy	Early 1982	
Franklin, KY	24,000,000	dry
Michigan Agri Fuels	Early 1982	
Alma, MI	10,000,000	dry
Midwest Solvents	Present	
Atchison, KS	3,000,000	dry
Pekin, IL	3,000,000	dry
	437,000,000	

It is interesting to note that all of these plants either have a tie in with an oil company (Pekin Energy - Texaco, South Point - Ashland Oil, Kentucky Agricultural Energy - Chevron, Michigan Agri Fuels - Total Petroleum) or have the capability to process their starch into at least one other product (besides fuel ethanol) such as high fructose corn syrup, beverage alcohol or industrial alcohol.

Production capacity of known smaller plants will be approximately 50,000,000 gal./yr. by year end 1982. Thus total productive capacity will approach 500,000,000 gallons per year by the start of 1983. If all the plants which have received tentative government approval for loan guarantees were built, with construction beginning immediately, there could be an additional 400,000,000 gallons of annual capacity by 1984. It is doubtful that all these plants will be built, and at present it appears unlikely that productive capacity will exceed one billion gallons before 1985, and even less likely that actual production will reach this amount.

At ADM and Staley, where high fructose corn syrup can be produced, fuel ethanol production plans may be influenced by the price of sugar. With low sugar prices, as at present, more fuel ethanol will be produced than with high sugar prices.

ADM, the major factor in fuel ethanol production, sells its production at 75 terminals in the U.S. The price at most midwest terminals has been approximately 3¢ a gallon above the Decatur, Illinois price. Whether this reflects true shipping costs or not, most smaller producers do not at present gain a significant advantage by being located closer to gasoline distributors, and may face increasing competition from ADM and other large producers. Since production costs at these large producers is probably under $1.10 a gallon, with corn at $2.50 (depending on how by-product credits are allocated), there is a great deal of leeway for further price cuts should competition for customers become more intense.

Appendix D

Real vs. Actual ("Nominal") Interest Rates

The implicit idea behind this discussion is that in times of varying inflation, constant interest "mortgages" are detrimental to someone. If inflation rates increase, the lender suffers. If inflation rates decrease, the borrower suffers.

In order to produce results which can be properly adjusted for future inflation, it is useful to express tham in "real" terms, i.e., by use of a real interest rate. Such results can then be converted to nominal (i.e., inflated) dollars, as we show below.

Justification for a real interest rate in the 2-3 percent range has already been mentioned [Dovring, et al., 1980]. Using it with the standard capital recovery factor, we find that a loan of value C requires n equal yearly pay units p of:

$$p \text{ (real)} = \frac{Cr}{1 - 1/(1+r)^n} \qquad \text{(D-1)}$$

where r is the real interest rate (per year) C and p are both expressed in real (or constant) dollars, appropriate to the year of the loan.

To modify Equation D-1 for inflation, we consider three cases.

1. Fixed interest loan, equal payments in nominal dollars.

Here the inflation rate in effect during the first year is locked in for all payments. The nominal interest rate is $(1+r)\ (1+i_1)-1$, where i_1 is the inflation rate in year one. (Note that the nominal interest rate is approximately, but not exactly, $i+r$). The payment p is obtained by letting $r \longrightarrow (1+r)\ (1+i_1)-1$ in Equation 1 to yield:

$$p \text{ (fixed interest with inflation)} = \frac{C[(1+r)\ (1+i_1)-1]}{1 - 1/(1+r)^n\ (1+i_1)^n} \qquad \text{(D-2)}$$

In times of high inflation, since $i \simeq 0.12$/yr. and $r \simeq 0.02$/yr., the difference between the result of applying Equation 2 instead of Equation 1 can be large, as pointed out in the text.

2. Variable interest loan, fixed pay back time.

This is a response to changing inflation rates; each year the payment is varied so that it is the same in real dollars and the loan is still paid off in n years. The payment (in nominal dollars) in year t is:

$$p_t \text{ (variable interest, with inflation)} = \frac{Cr}{1-1/(1+r)^n} (1+i_1)(1+i_2)\ldots(1+i_t) \tag{D-3}$$

where i_t is the inflation rate in year t. In this scheme payments can increase (in nominal terms) very fast if inflation continues. On the other hand, if deflation occurs, i.e., if i becomes negative for some years, the nominal payment can diminish.

3. Another response to variable interest is to keep the nominal payments fixed but vary the payback time. We do not use this approach in the text, since we want to assume a fixed payback period, but we discuss the mathematics below.

If the cost C were instead invested, in n years its value (in nominal dollars) would be:

$$C\ (1+r)^n\ (1+i_1)\ (1+i_2)\ (1+i_3)\ \ldots\ (1+i_n) \tag{D-4}$$

On the other hand, if each time the constant payment p (in nominal dollars) were similarly invested in an account drawing the same interest, after n years that account would hold (in nominal dollars):

$$p(1+r)^{n-1}\ [(1+i_1)\ (1+i_2)\ \ldots\ (1+i_{n-1})] +$$
$$p(1+r)^{n-2}\ [(1+i_1)\ (1+l_2)\ \ldots\ (1+i_{n-2})] + \ldots.. +p \tag{D-5}$$

p can be set at any reasonable level and then expressions D-4 and D-5 can be equated and solved for n, the payback period.

The discussion of real interest rates in Section II of the text is based on the difference between Equations D-1 and D-2.

Table 1. Costs of Production

Food and Energy, Inc.
Litchfield, Michigan
August 1981

Annual capacity: 1,200,000 gallons of 200° ethanol

Capital structure: Subchapter S Corp. with $500,000 in equity financing and $350,000 of bank loans at 1 percent above the prime rate

Yield of 200° ethanol per bushel of corn: 2.35

Recovery of distillers grains (and some solubles) per bushel: 13.5 pounds

Corn price: $2.50/bu. Wet distillers grains sales price - 7¢/lb.
Average sales price for ethanol - $1.80

All costs in $/gallon.

Cost of:	Actual figures for Aug. 1981 production Interest only was being paid on debt 49,355 gal/mo produced	Assuming all capital ($850,000) was debt at 16% amortized over 10 yr. period 49,355 gal/mo produced	Base case Assumes plant operating at full capacity of 100,000 gal./mo. Real rate of interest of 3% on all capital ($850,000)
Corn[1]	.66	.66	.66
Fuel-natural gas $3.53/1000ft.	.15	.15	.15
Electricity	.06	.06	.06
Chemicals, yeasts enzymes, water	.15	.15	.15
Maintenance[2]	.07	.07	.04
Sieve material[3]	.03	.03	.03
Labor[4]	.42	.42	.20
Capital	.14	.29	.08
	$1.68	$1.83	$1.37

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[1] *A DG credit of $.40 per gallon has been subtracted from the $1.06 per gallon cost of corn.*

[2] *During August several pumps were replaced (a common problem in ethanol plants), and this was reflected in August costs. For the base case annual maintenance costs were assumed to be 5% of the total capital cost of the plant (USDA 1980). This includes local taxes and insurance.*

[3] *Assumes one year useful lifetime of sieves. See Appendix A on use of molecular sieves.*

[4] *It has been assumed that this plant could produce at capacity without additional labor.*

Table 2. Cost of Production

Plant X
September 1981

Annual capacity: 1,500,000 gallons of 192° ethanol

Capital structure: Partnership, $590,000 in loans guaranteed by the SBA, at the prime rate. $195,000 equity

Yield of 192° ethanol: 2.57 gallon/bushel

Recovery of distillers grains: 8 pounds dry weight per bushel
Wet distillers grains sales price 7¢ pound dry weight

Corn price: $2.50

October selling price of ethanol output: $1.51 per gallon

All costs $/gallon.

Cost of:	Actual cost[1]	Conventional loan[2]	Base case[3]
Corn[4]	.75	.75	.75
Fuel-propane $.51 per gallon	.20	.20	.20
Electricity	.02	.02	.02
Chemicals, yeasts, enzymes, water	.13	.13	.13
Maintenance[5]	.03	.03	.02
Labor[6]	.19	.19	.15
Capital	.12	.19	.05
	$1.44	$1.51	$1.32

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[1] *For monthly production of 72,000 gallons. Interest only was being paid on the loan of $590,000.*

[2] *Assumes a loan of $785,000 (total plant cost) at 16% amortized over the ten year plant lifetime, production at 72,000 gal./mo.*

[3] *Assumes production at full capacity of 125,000 gal./mo., and a real rate of interest of 3 percent on $680,000 amortized over a ten year period. The $105,000 spent for the salt process ethanol drying system has not been included in capital costs here.*

[4] *A DG credit of $.22 per gallon has been subtracted from the $.97 cost of corn per gallon.*

[5] *Assumed to be 5 percent of total capital cost for base cases, including local taxes and insurance.*

[6] *The plant has been operating on a five day per week schedule. It was assumed that full production could be reached with 7/5 of this monthly payroll.*

Table 3. Cost of Production

Mid States Energy Resources
Lanark, Illinois
January 1982

Annual capacity: 625,000 gallons of 200^0

Capital structure: Partnership $225,000 equity, $225,000 bank and personal loans at 1 percent above the prime rate

Yield: 2.61 gal/bu. 190^0, 2.48 gal/bu. 200^0

Recovery of distillers grains: 11 lbs/bu. dry weight

Corn price: $2.50/bu.

Wet distillers grains sales price: 7¢/lb. dry weight

All costs in $/gallon.

Cost of:	Actual figures 1/ 190^0 14,450 gal/mo produced	Conventional 2/ Loan 190^0 14,450 gal/mo produced	Base Case 3/ 190^0 52,083 gal/mo produced	Base Case 4/ 200^0 52,083 gal/mo produced
Corn	.66	.66	.66	.70
Fuel--natural gas $4.05/1000 ft^3	.16	.16	.16	.18
Electricity	.03	.03	.03	.04
Chemicals, yeasts, enzymes, water	.11	.11	.11	.11
Maintenance 5/	.04	.04	.04	.04
Sieve material 6/	.00	.00	.00	.01
Labor 7/	.18	.18	.13	.13
Capital	.16	.38	.06	.08
	$1.34	$1.56	$1.19	$1.29

1/ *Based on November 1981 operation, interest only being paid on loans of $155,000. Two employees were drawing $300 per week salary.*

2/ *Assumes a 16% loan on total capital cost of $315,000 for the* 190^0 *plant, amortized over 10 years.*

3/ *Assumes a real rate of interest of 3% on the $315,000 capital cost amortized over 10 years.*

4/ *Assumes a real rate of interest of 3% on the $450,000 total capital cost for the* 200^0 *plant amortized over 10 years.*

5/ *Assumed to be 5% of total capital cost for base cases.*

6/ *The manufacturer of the dehydrator expects the sieve material to last 5 to 7 years. A lifetime of one year has been used for the base cases. While this may seem very short, there is little operating experience with molecular sieves. In any case, even with this assumption the sieve material costs only $0.01/gal.*

7/ *Salaries of present employees are expected to rise if the plant becomes profitable. An estimated annual payroll of $80,000 for five employees is used for base cases.*

Table 4. Uncertainty Analysis For Food and Energy, Inc.

	$\frac{\partial C}{\partial X_i}\frac{X_i}{C}$	Base case values of X_i	Expected range of fractional uncertainty of X_i		Expected fractional uncertainty from input X_i	
			$\frac{\Delta X_i^+}{X_i}$	$\frac{\Delta X_i^-}{X_i}$	$\frac{\partial C}{\partial X_i}\frac{\Delta X_i^+}{C}$	$\frac{\partial C}{\partial X_i}\frac{\Delta X_i^-}{C}$
C_g	.59	$2.50/bu.	1.00	-.10	.59	- .059
C_f	.11	$ .15/gal.	1.00	0	.11	0
C_e	.04	$ .06/gal.	.25	0	.01	0
C_c	.11	$ .15/gal.	.03	0	.003	0
C_m	.03	$ .04/gal.	1.00	0	.03	0
C_s	.02	$ .03/gal.	.03	0	.0006	0
C_L	.15	$ .20/gal.	.05	0	.0075	0
C_I	.06	$ .71/gal.	0	0	0	0
R_{bu}	-.29	13.5/lbs.	0	-.11	0	.032
Y_{bu}*	-.48	2.35 gal/bu	.06	0	-.027	0
d*	-.32	1	0	-.4	0	.104
r*	.01	.03	1.00	-.33	.01	-.0033
n*	-.05	10 years	.2	-.2	-.01	.01

* *C has a non-linear dependence on the factors Y_{bu}, d, r, and n. $\partial C/\partial X_i$ was taken at the base case values for Y_{bu}, r, and n. However, for d, $\partial C/\partial d$ was taken at d = .8, which is the midpoint of the expected range in d (from .6 to 1).*

Table 5. Estimated Cost of 200° Ethanol Production at Food and Energy, Inc. ($ 1981 /gal.)

Corn Price $/bu.	$d\left(\frac{\text{annual production}}{\text{annual capacity}}\right)$		
	1	.8	.6
2.25	1.29	1.36	1.48
2.50	$\boxed{1.37}$	1.44	1.56
2.75	1.45	1.52	1.64
3.00	1.53	1.60	1.72
3.25	1.61	1.68	1.80
3.50	1.69	1.76	1.88
3.75	1.78	1.85	1.97
4.00	1.85	1.93	2.05
4.25	1.94	2.01	2.13
4.50	2.02	2.09	2.21
4.75	2.10	2.17	2.29
5.00	2.18	2.25	2.37

Table 6. Maximum Corn Price for Production Cost of Less Than $1.70/gal. 200°, ($ 1981/bu.)

Cost of Input Fuel (1981 $)	$d\left(\frac{\text{annual production}}{\text{annual capacity}}\right)$		
$/gal.	1	.8	.6
.15	3.51	3.30	2.93
.20	3.35	3.14	2.78
.25	3.20	2.99	2.63
.30	3.05	2.83	2.47

Table 7. Estimated Cost of 200° Ethanol Production At The Model Plant ($ 1981/gal.)

Model plant base case costs $1.30/gal. R_{bu} = 12 lb./bu. Y_{bu} = 2.5 gal. 200°/bu.
Annual capacity - 1,500,000 gallons 200° ethanol
Corn price $2.50/bu.

Cost of Corn $/bu.	$d\left(\frac{\text{annual production}}{\text{annual capacity}}\right)$		
	1	.8	.6
2.25	1.22	1.28	1.38
2.50	1.30	1.36	1.46
2.75	1.38	1.44	1.54
3.00	1.46	1.52	1.62
3.25	1.54	1.60	1.70
3.50	1.62	1.68	1.78
3.75	1.69	1.75	1.85
4.00	1.77	1.83	1.93
4.25	1.85	1.91	2.01
4.50	1.93	1.99	2.09
4.75	2.01	2.07	2.17
5.00	2.09	2.15	2.25

Table 8. Maximum Corn Price for Production Cost of Less Than $1.70/gal. 200° Ethanol ($ 1981/bu.)

Cost of Input Fuel (natural gas) $/gal.	$d\left(\frac{\text{annual production}}{\text{annual capacity}}\right)$		
	1	.8	.6
.15	3.75	3.56	3.24
.20	3.59	3.40	3.08
.25	3.43	3.24	2.93
.30	3.27	3.08	2.77

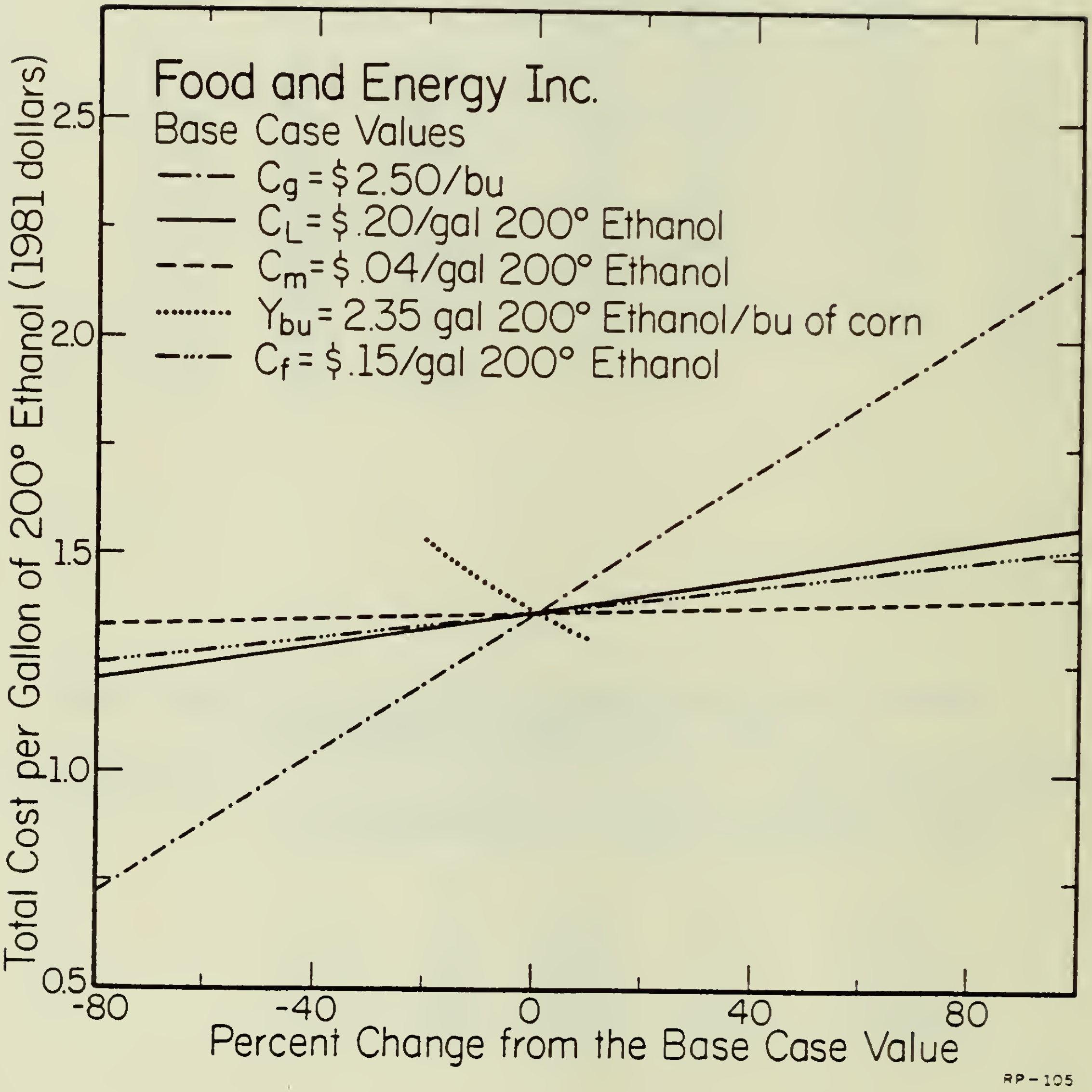

Figure 1a. Sensitivity Analysis

Each line shows the variation in cost per gallon if that respective input is varied. This plant does produce 200° ethanol.

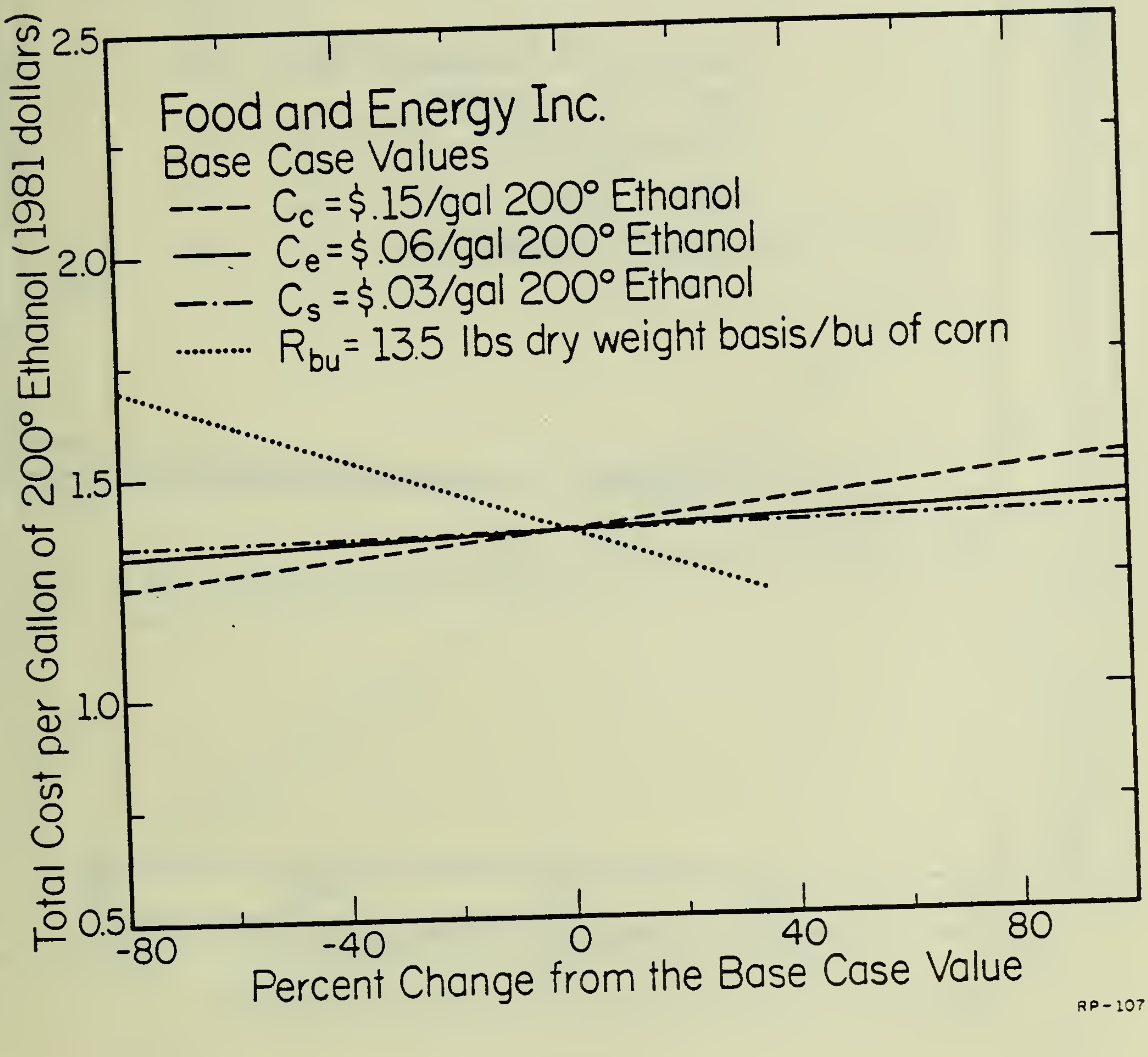

Figure 1b.

Each line shows the variation in cost per gallon if that respective input is varied. This plant does produce 200° ethanol.

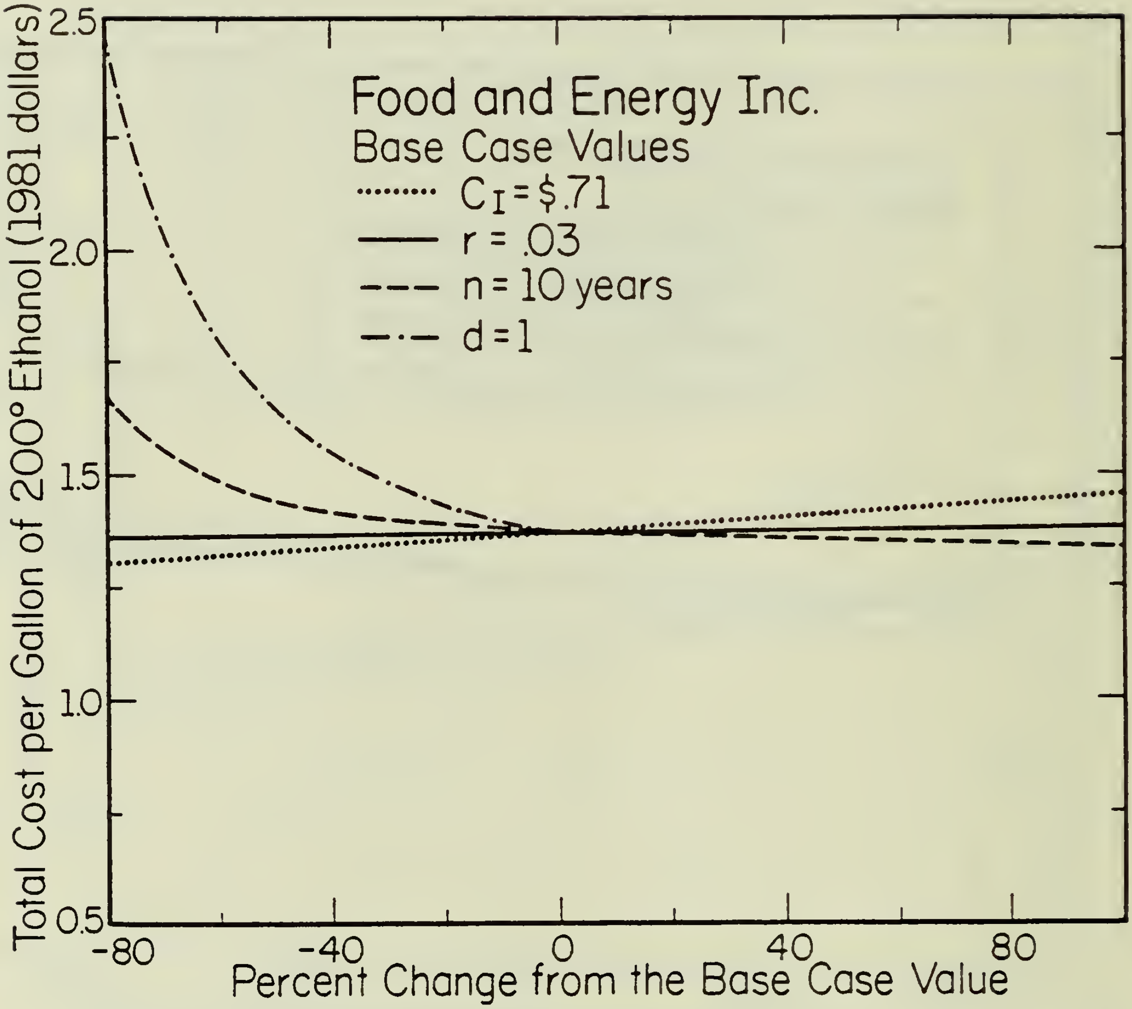

Figure 1c.

Each line shows the variation in cost per gallon if that respective input is varied. This plant does produce 200° ethanol.

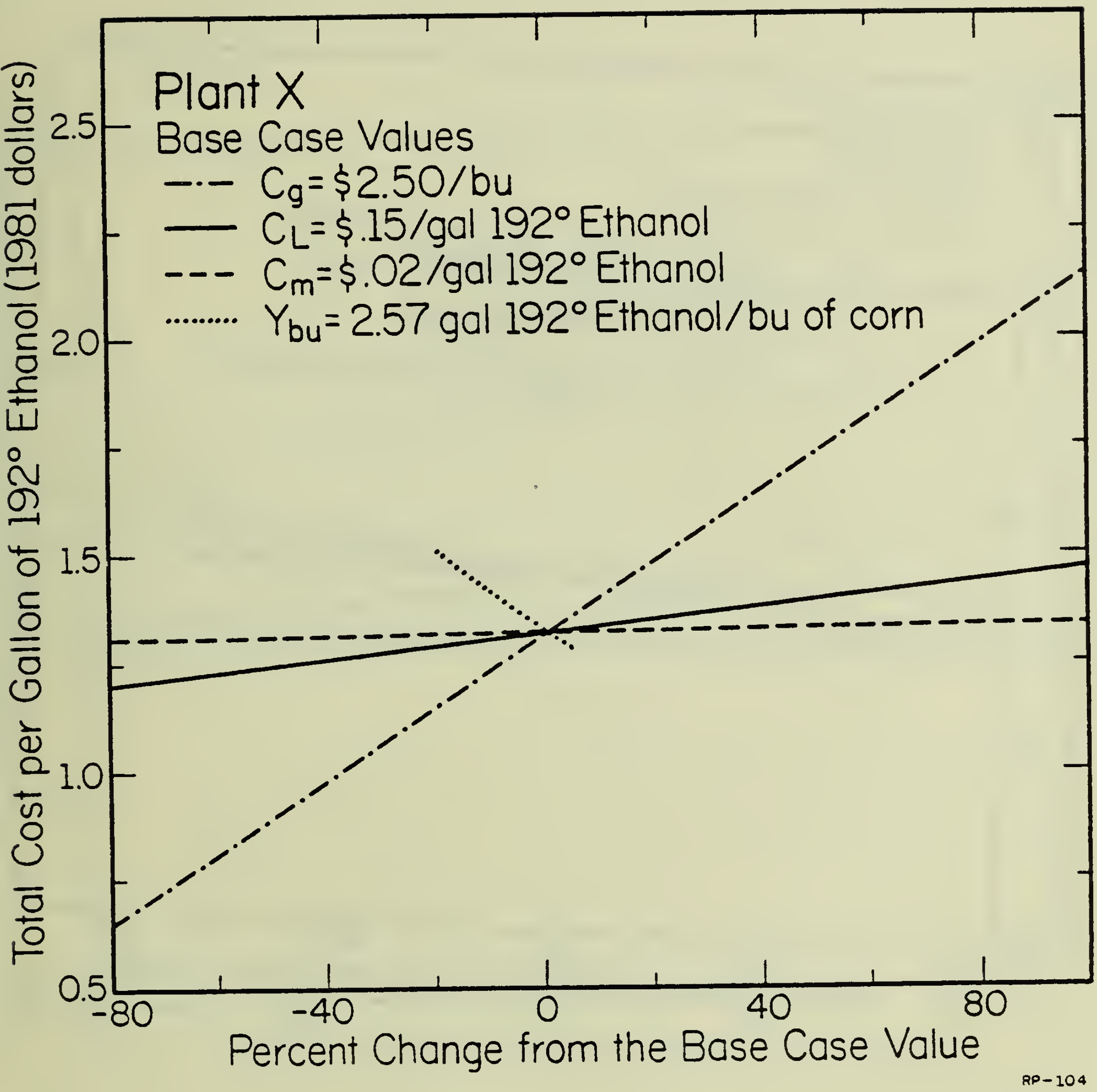

Figure 2a. Sensitivity Analysis

Each line shows the variation in cost per gallon if that respective input is varied. This plant actually produces 192° ethanol.

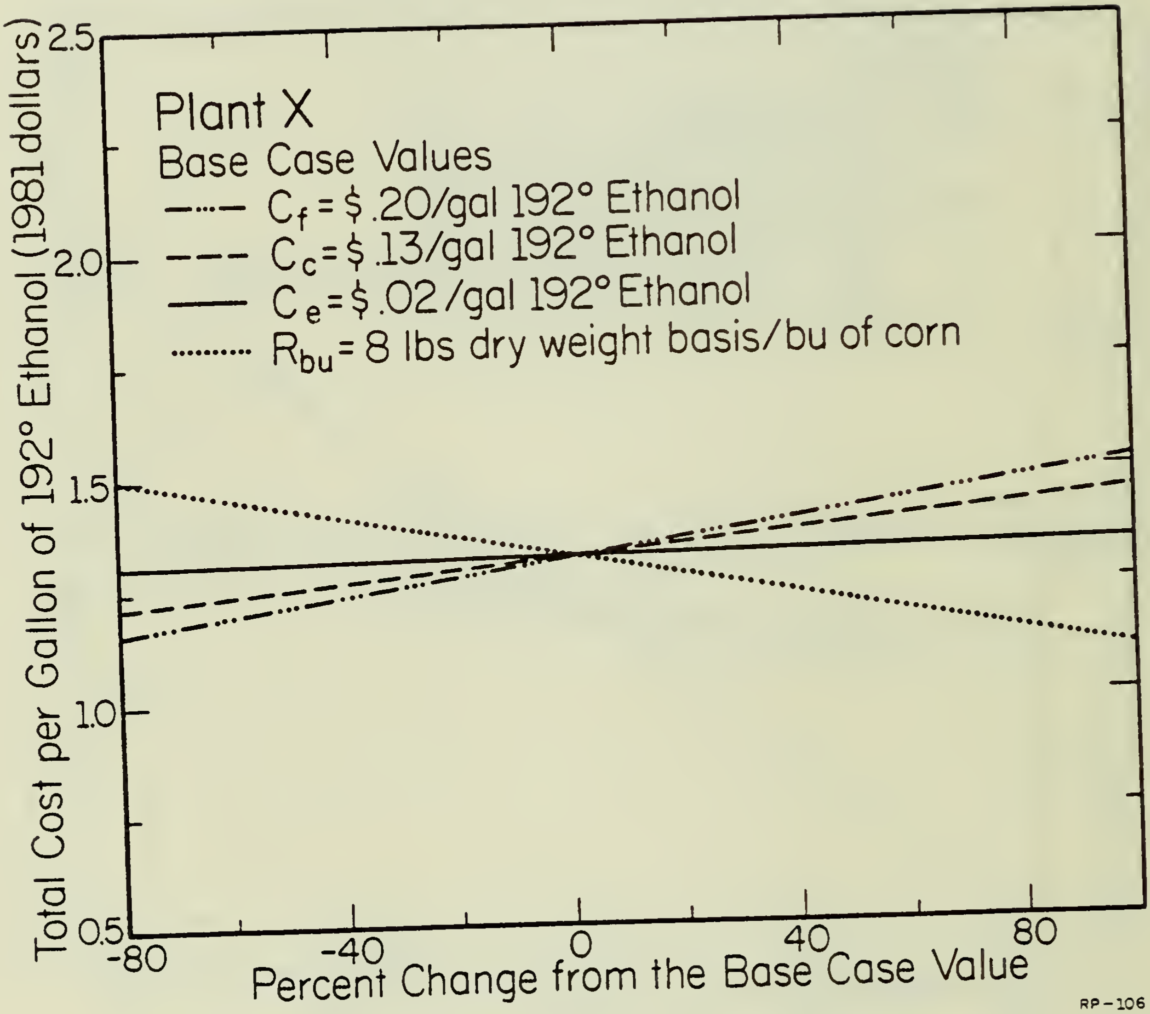

Figure 2b.

Each line shows the variation in cost per gallon if that respective input is varied. This plant actually produces 192^0 ethanol.

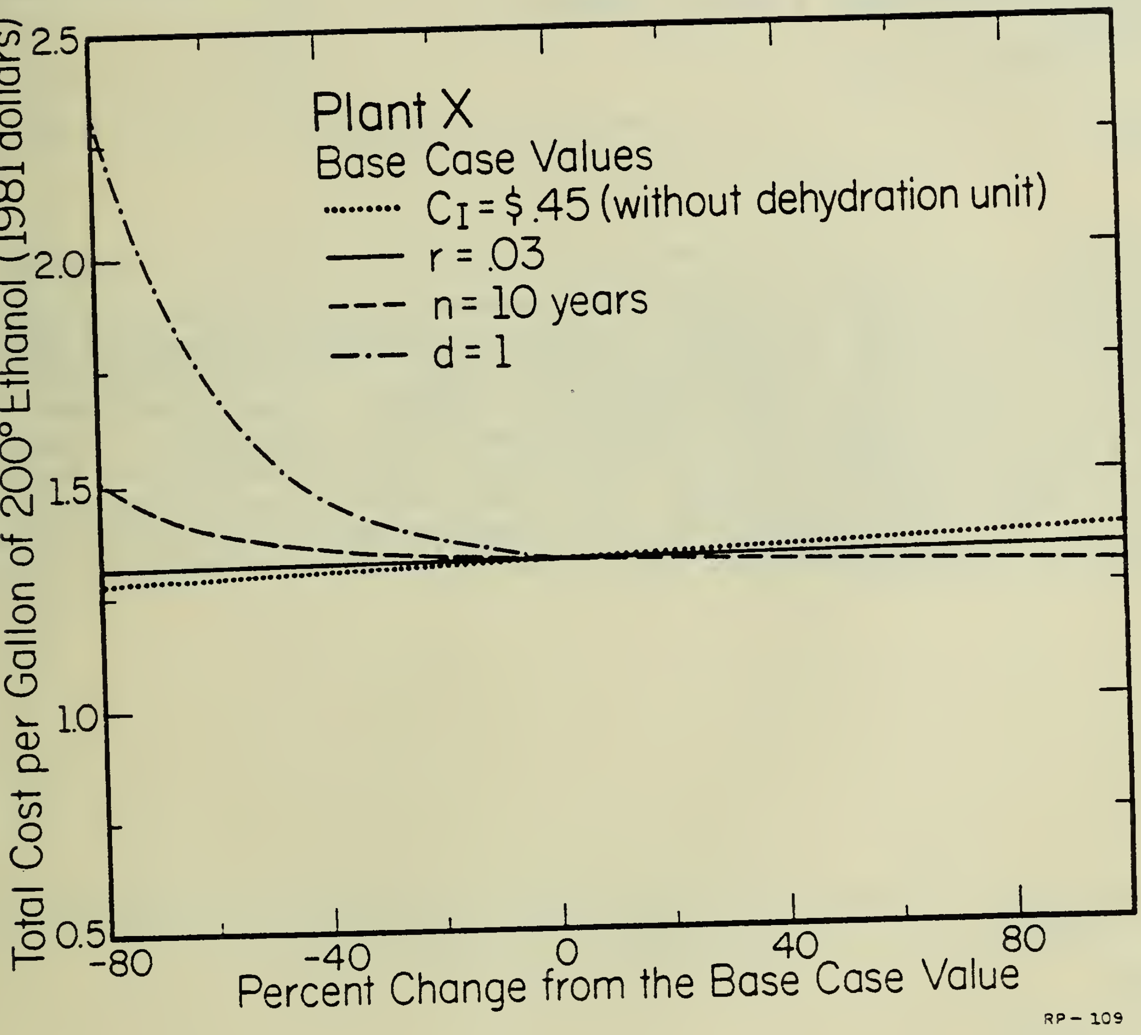

Figure 2c.

Each line shows the variation in cost per gallon if that respective input is varied. This plant actually produces 192° ethanol.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. 82/16	2.	3. Recipient's Accession No.

4. Title and Subtitle
Economic Balances of Small Scale Ethanol from Biomass Operations

5. Report Date
July 1982

6.

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address
University of Illinois
Department of Agricultural Economics
Urbana, Illinois 61801

10. Project/Task/Work Unit No.
80.224

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
Illinois Department of Energy & Natural Resources
325 West Adams
Springfield, Illinois 62706

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The study analyzed the economic viability and operational and marketing conditions of three Midwestern grain-based fuel ethanol plants with production capacity of less than 1.5 million gallons per year. Results on capital costs, operational experiences, and marketing of fuel ethanol and feed byproducts are presented. These plants were found to have many similar characteristics, including low initial capital costs. However, additional capital requirements for the installation of ethanol dehydration equipment presented substantial cash flow problems. Most fuel ethanol plants studied were operating at less than production capacity due to unstable market conditions. The economic feasibility of the grain-based ethanol plants studied was determined to be marginal.

17. Document Analysis a. Descriptors
ethanol
fuel alcohol
production
economic feasibility

b. Identifiers/Open-Ended Terms
biomass
gasohol
commercialization
byproducts

c. COSATI Field/Group

18. Availability Statement:
No restriction on distribution

19. Security Class (This Report)
not classified

20. Security Class (This Page)
not classified

21. No. of Pages
64

22. Price

(See ANSI–Z39.18)

OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

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3 0112 042099561

The HF Group
Indiana Plant
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2/7/2007

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3 0112 081624303